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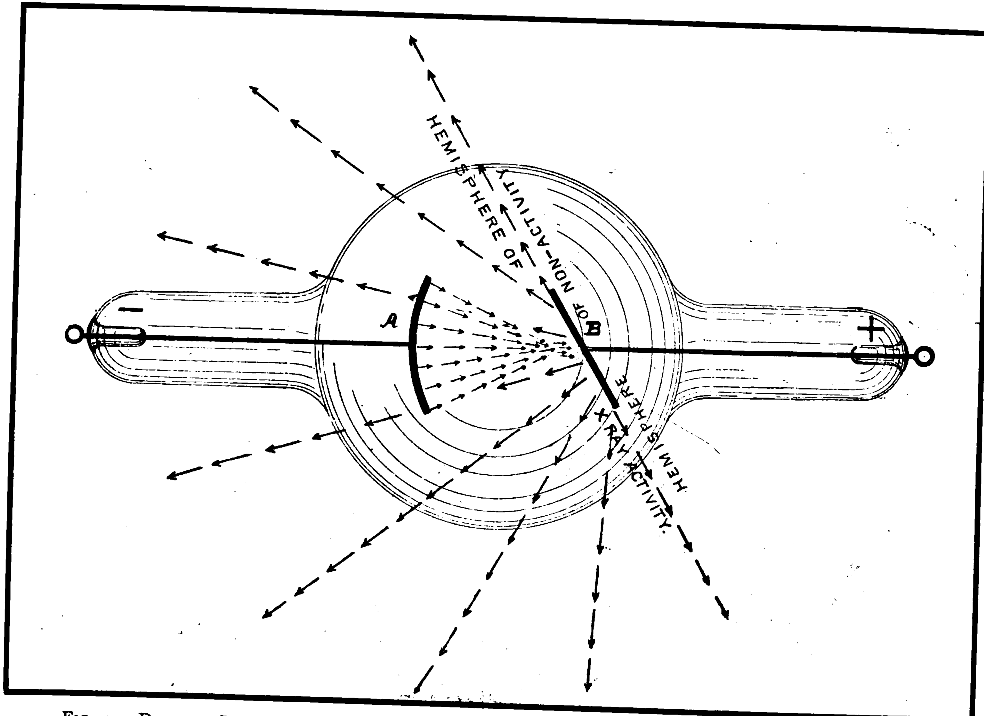

Fig. 52. Diagram Showing Production of X Rays (Red) by Impingement of Cathodic Stream (Blue) upon the Anti-Cathode.

THE X RAY

124203

OR

PHOTOGRAPHY OF THE INVISIBLE

AND

ITS VALUE IN SURGERY

BY

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WRITTEN IN COLLABORATION WITH

EDWIN W. HAMMER

Electrical Engineer

NEW YORK

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THE X RAY

COMPOSITION AND ELECTROTYPING
BY
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PART I.—DEFINITIONS.

PART II.—APPARATUS.

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PART IV.—SURGICAL VALUE OF THE X RAY.

PUBLISHERS' NOTE.

The world-wide interest that has been taken in Prof. Roentgen's discovery of the marvellous properties of the X Ray prompted the publishers of this work to call on Dr. William J. Morton of New York, who had already been acknowledged the best X Ray expert in the United States, and urge him to write the result of his investigations with the X Ray for the benefit of the many who desired reliable information on this scientific discovery.

The publishers have endeavored to present the work to the public in a style which will be in keeping with the importance of the subject.

All of the line illustrations contained in the work are from the dictation of the writers, and the half-toned plates are reproduced mechanically direct from the negatives of X Ray radiographs, taken by Dr. Morton. Much of the sharpness and delicacy of the original negatives has been lost in the reproduction, as it is impossible to make exact copies of the negatives.

Mr. Edwin W. Hammer, Electrical Engineer, has rendered valuable assistance in the preparation of the work.

As many doctors, surgeons, dentists and others are contemplating the addition of the X Ray apparatus to their laboratories, Dr. Morton would be pleased to give any information gained by his experiments on the selection of the best material, and thus save them loss of time and money in experimenting with inferior apparatus. His address is Corner of Madison Avenue and 28th Street, New York City.

LIST OF ILLUSTRATIONS.

LINE DRAWINGS.

HALF TONE PHOTOGRAPHIC PLATES (at end of book).

PREFACE.

There are some discoveries of a purely scientific nature that appeal only to a limited class, while others broadly affect the life and happiness of the human race and thus become of universal importance.

The discovery of Prof. Roentgen is unique in that it interests alike the scientific and non-scientific intelligent minds of all countries. To the world of science new problems as to the constitution of matter and the innermost secrets of electricity are suggested, while to the race at large is opened up a new means of diagnosis and relief of suffering and disease in the field of surgery. No wonder, then, that interest in this subject is universal.

It is in the hope of satisfying the craving for information concerning the subject, even if but to a limited extent, that this elementary little book has been prepared. The difficulties which have beset the way will be only too apparent to those who have experimentally followed the progress of the X Ray since its discovery, due to

the fact that its phases have changed from day to day and are still changing. Under these circumstances the writers can only ask from the reader kindly consideration for their work. What is here written in special regard to the X Ray is based upon Dr. Morton's actual and personal experimentation, even to the negatives from which the half-tone reproductions have been made. These in no instance have been retouched, but are purely mechanical reproductions.

W. J. M.
E. W. H.

New York, Sept. 1th, 1896.

PART I.—DEFINITIONS.

CHAPTER I.

THE VOLT.

MANY people feel that because they know nothing of a subject it must follow that it is very hard to understand. Anything of an electrical nature is viewed with especial awe because of the supposed mystery that surrounds it. It is true that we do not know just what electricity is, but neither do we know with certainty the why and wherefore of the other forces of Nature. If you are asked why an apple, loosened from its position on the tree, falls to the ground, you may answer: "Because of the attraction of the Earth for the apple." But why has the Earth this attractive power? "Because," you will say, "of the Law of Gravitation." This is very true, but can you tell *why* each particle of matter in this universe gravitates toward every other particle? No! and there is no one who can. But we know the apple *does* fall to the ground, and we are able

to make use of the Law which governs its fall in very many ways.

So, although we are not sure as to just what electricity is, we do know how to produce it and how to bend it to our will, forcing it to send messages around the world or to light up our streets and houses, to run our trolley cars or produce the wonderful X Rays.

Electricity, like other forces, can be measured, and as its nature is different from that of other forces we must express its measurements in different terms. Not being a substance, electricity has no length, breadth or thickness, but it has other qualities which we should consider before going further. The first of these qualities is *pressure.*

If you have a water-tank on the roof of your house and a pipe leading from it to the different floors, you will find that the water will flow from the faucet on the ground floor in a stronger stream than from the faucet on the top floor. This is because the lower you go the greater is the *head* or *pressure* of the water. This pressure is due to the weight of the column of water in the pipes and is measured in *pounds per square inch.*

In similar manner, if we have a source of electricity we will find that the electricity there

produced will also be under *pressure* and will try to "find its own level" just as the water in the pipes does. In the water system the supply at the highest point is always trying to reach the level of that at the lowest point, and the greater the difference in height between the upper and lower points the greater will be the *water pressure.* In the electric system the electricity at the point most highly charged is always trying to find its way to the point least charged, and the greater the difference between these two points the greater will be the *electrical pressure.* This pressure is sometimes called *tension* or *potential difference* or *electromotive-force.*

A certain amount of water pressure will be *One Pound* per square inch; a certain amount of electrical pressure will be *One Volt.* Electrical pressure cannot be measured in *pounds*, so we say, for convenience, that it will be measured by a unit which might have been given any name but which electricians call the *Volt.* It is about the electrical pressure given off from one cell of Daniell's battery.[1] So if you are asked what the Volt is, you can answer:

The Volt is the practical unit of Electrical pressure.

[1] For a description of the Daniell battery see page 35.

CHAPTER II.

THE AMPÈRE AND THE COULOMB.

WE have just seen how the force of a stream of water would be greater on the ground-floor of your house than on the top-floor if the supply tank is on the roof, due to the difference in pressure. And if you stop to consider you will see that the water is coming out at the ground-floor more quickly or at a greater *rate* than it would on the top-floor. In other words, when you open the lower faucet the water may flow out of the pipe at the *rate* of 600 gallons an hour, although you may only allow the stream to flow for one minute. In this case the *quantity* of water which would flow would be 10 gallons. Is this distinction between *rate* of flow and *quantity delivered* perfectly clear to you?

Use another thought in this connection. You may be travelling on the Empire State Express-train and ask the conductor how fast you are moving. He might say, "We are travelling at this moment at the *rate* of six thousand feet a

minute." But you can see that you will not have travelled six thousand feet unless the same *rate* of movement is continued for an entire minute.

In a similar manner we have a current of electricity flowing along under a pressure of a certain number of volts and that *pressure* will cause the current to flow at a certain *rate.* If that *rate* of flow is continued for a certain length of time a definite *quantity* of electricity will have passed.

We measure the *rate* of electrical flow by a unit we call the *Ampère* and the *quantity* that flows by a unit known as the *Coulomb.* When a current of electricity is flowing at the *rate of One Ampère* for an entire second, a *quantity* known as *One Coulomb* will have passed.

Therefore :—*An Ampère is the practical unit of rate of flow of electric current ;*

A Coulomb is the practical unit of electrical quantity.

CHAPTER III.

THE OHM.

It takes more of an effort to drag a box holding a hundred pounds of earth along the road than a wheeled cart holding the same load.

A sewing-machine runs more easily when it is oiled up than when all the bearings are dry.

More water will flow in ten minutes out of a large pipe connected to your roof-tank than out of a small pipe connected to the same tank.

More water will flow in ten minutes from any pipe when the faucet is opened wide than when only half opened.

The box meets with more *friction* or *opposition* or *resistance;* the dry bearings of the sewing-machine also present greater obstacles for the same reason; the small water pipe and the half opened faucet also mean more *resistance* to the flow of water.

We measure frictional resistance by the work required to overcome it.

Every current of electricity must flow along some path or through some substance, such path being known as a *conductor*. All substances are not equally good as conductors. For instance, metals are better conductors of electricity than other substances, and some metals are better conductors than other metals; iron is better than carbon, copper is better than iron, silver is better than copper. The better the conductor the less *resistance* it offers to the passage of an electric current, when both conductors are of the same length and area in cross-section. The resistance which a conductor of a given size offers, as compared with a conductor of the same size but of a different material, is known as its *Specific resistance.*

But a conductor of given size will have a different resistance from another conductor of the same material but of different dimensions. If we have two round copper wires, one 50 feet long and the other 100 feet long, but each having the same diameter, the resistance of the piece 100 feet long will be *twice* as great as the piece 50 feet long. If we have two round copper wires each 100 feet long but one having a diameter twice as great as the other, the conductor having the smaller diameter will have *twice* the resist-

ance of the other. So we see that the *greater the length* the *greater the resistance* and the *greater the diameter* the *less the resistance.* We measure electrical resistance by a unit called the *Ohm*, which is of such a character that an electrical conductor having a resistance of *one ohm* will permit current to flow through it at the rate of *one ampère* when under a pressure of *one volt.* This intimate connection between the *volt*, the *ampère* and the *ohm* is expressed in Ohm's Law, as follows: Current (in ampères) equals the Electromotive-Force (in volts) divided by the Resistance (in ohms). If $C = \frac{E}{R}$ then $E = C \times R$ and $R = \frac{E}{C}$. So you see that if you know what any two of the terms are you can find the third term.

Example: What is the resistance of a conductor through which 10 ampères are passing under a pressure of 50 volts?

Answer: $R = \frac{50}{10} = 5$ ohms.

Example: How many ampères will flow through a conductor having a resistance of 25 ohms under a pressure of 100 volts?

Answer: $C = \frac{100}{25} = 4$ ampères.

Example : How many volts will be required to force 15 ampères through a resistance of 2 ohms? *Answer:* $E = 15 \times 2 = 30$ volts.

Therefore :—

The Ohm is the unit of electrical resistance.

CHAPTER IV

THE WATT.

WHEN we raise 1 pound through 10 feet of space we perform a certain amount of *work* which is the same whether we take 10 minutes or 100 minutes in which to do it. But the *rate of doing work* or *power expended* is very different in the two cases, being 10 times as great in the first as in the second. So you see there is an important difference between *work* and *power*. When we raise 1 pound 33,000 feet in one minute we are working at the *rate* of 1 Horse-Power. The 1 pound multiplied by 33,000 feet equals 33,000 *foot-pounds;* 33,000 pounds multiplied by 1 foot also equals 33,000 foot-pounds, as does 1,100 pounds multiplied by 30 feet. In fact, any product of pounds and feet equalling 33,000 when expended in *one minute* equals 1 Horse-Power.

In a similar manner a current of electricity can perform work and its rate of doing work is measured by multiplying the pressure, in volts, by the rate of current flow, in ampères, the resulting

product being expressed by the unit called the *Watt.* Thus, a current flowing at the rate of 1 ampère under a pressure of 1 volt is doing work at the rate of 1 watt. The watt is the equivalent of $\frac{1}{746}$ of a horse-power, because it is the power required to perform 44.25 foot-pounds of work in a minute, which is $\frac{1}{746}$ of 33,000 foot-pounds. In other words, 746 watts make 1 electrical horse-power. The watt is sometimes called the *volt-ampère.*

Example: If a generator of electricity is supplying 40 ampères at a pressure of 100 volts, how many watts is it developing? *Answer:* 100 volts x 40 ampères = 4,000 watts.

Example: If a generator is supplying 373 ampères at 100 volts, how many electrical horse-power is it developing? *Answer:* 373 x 100 = 37,300 watts ÷ 746 = 50 horse-power.

Therefore:—

The Watt is the unit of electric power or rate of doing electrical work.

CHAPTER V.

CAPACITY AND THE MICROFARAD.

WHEN we take a glass jar of a given size and pump air into it with a force pump we do two things: 1st, we increase the quantity of air in the jar, and 2nd, we increase the pressure inside the jar. The pressure thus produced is dependent upon the size of the jar and the quantity of air forced in, and is greater the smaller the size of the jar and the greater the quantity of air forced in.

In a similar manner, when we force electricity into a conductor we produce a certain difference of potential or pressure which depends on the *capacity* of the conductor. So, the smaller the capacity of a conductor, the smaller is the charge required to raise it to a given pressure, and the higher the pressure to which a given charge will raise it.

The *capacity* of a conductor is measured by the practical unit called the *Farad* which is such a capacity that one coulomb of electricity is re-

quired to produce in the conductor a pressure of one volt.

The charge of electricity acts just like the air in the jar we have spoken of above; it appears to be so very compressible that the quantity required to fill any conductor will depend on the pressure under which it is applied.

The *Farad* is such a very large unit that for ordinary purposes we use the $\frac{1}{1000000}$ of a farad which we call the *Microfarad*.

CHAPTER VI.

INDUCTION.

INDUCTION may, in general, be said to be *that influence which one magnetized or electrified body or conductor may have upon another body or conductor when the two are not in actual contact.*

Almost every useful electrical device is dependent upon this principle of induction in some form or other. So important is it, indeed, that we cannot do better than examine some of its effects.

(1) As is well known, every magnet has a North (N) and a South (S) pole. A N pole of one magnet will not attract the N pole of another, neither will one S pole attract another S pole; but any N pole will attract any S pole and *vice versa.* Therefore, *like poles repel, unlike poles attract each other.* If we take an ordinary horseshoe magnet such as can be bought in toy-

stores we will find that either one of its poles will pick up a small iron nail, as in Fig. 1. If we tip the magnet a little so as to swing the free end of the nail up against the other magnet-pole, as in Fig. 2, we find the nail will stick there firmly. This is because when the one pole (say the N pole) of the magnet is brought near the point of

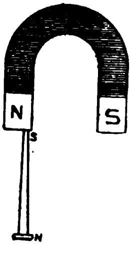

FIG. 1.

the nail it *induces* magnetism in the nail giving it a N and a S pole, the S pole of the nail being nearest the N pole of the horse-shoe magnet. Then as unlike poles attract, the free (or N) pole of the nail will be attracted to the other (or S) pole of the magnet. This magnetic induction can be carried further by making the nail induce magnetism in a second nail and that in, we will say, a carpet tack, as in Fig. 3.

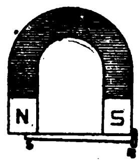

FIG. 2.

(2) When a current of electricity passes through a conductor it makes a magnet of the conductor by setting up or inducing a whirl of magnetic lines of force around it, as shown in Fig. 4. The direction of these whirls can be easily remembered; if the current

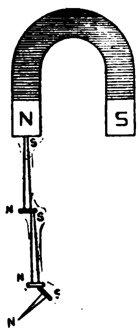

FIG. 3.

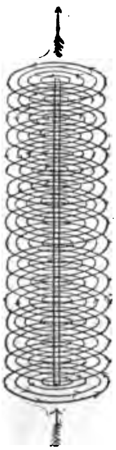

FIG. 4.

flows towards you the whirls travel around in a direction opposite the hands of a clock, as in Fig. 5. If, instead of using a straight conductor, we coil it up in the form of a solenoid as in Fig. 6 we increase the magnetic effect because every turn of the conductor *induces* increased magnetism in every other turn. Such a solenoid possesses all the characteristics of a steel magnet but only while the current of electricity is passing through it. The N pole of the solenoid is that end where, when you look down upon it, the current is travelling around in a direction opposite the hands of a clock.

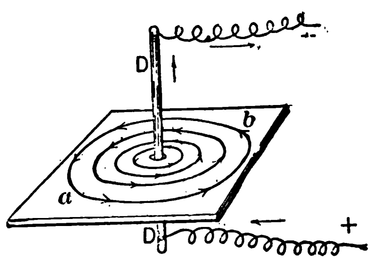

FIG. 5.

(3.) If we wind the conductor from our source of electricity around a bar of soft iron as shown in Fig. 7 we induce magnetism in the bar as well as in the coil, the polarity being the same in both. The presence of the iron increases

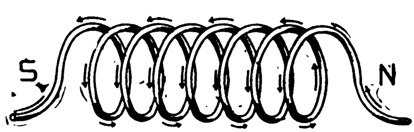

FIG. 6.

the total magnetic strength amazingly, due to the iron being a magnetic metal and gathering to it all the available lines of magnetic force induced by the passage of the electric current through the solenoid.

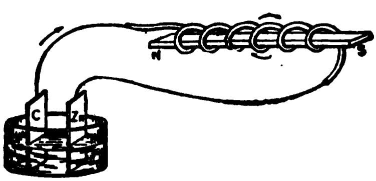

FIG. 7.

The soft iron is said to increase the magnetic effect, under proper conditions, to as much as 32.8 times. As in the case of the simple solenoid, magnetism is only present here while a current of electricity is flowing through the conductor, such combination of coil and bar is known as an electro-magnet.

(4.) If we connect a coil of wire to a *galvanometer* or electric indicator and move a steel bar-magnet towards the coil we will *induce* a *momentary current* in the coil, as will be shown by a movement of the galvanometer needle; if we now draw the permanent magnet away from the coil another momentary current will be induced but in the *opposite direction*. This arrangement is clearly shown in Fig. 8, where M is the magnet, PP the coil, and S the indicator or galvanometer.

(5.) If the magnet is stationary and we move

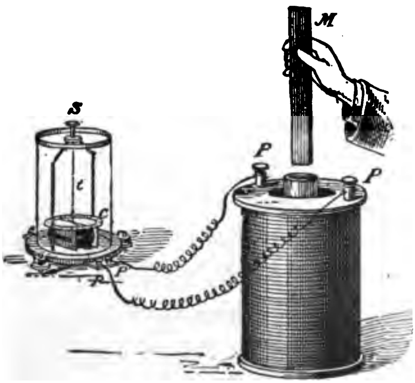

Fig. 8.

the coil back and forth we get similar results to those in section 4. That is, when we move the coil towards the magnet we induce a momentary current in one direction and when we draw the coil away from the magnet we induce a momentary current in the other direction.

(6.) As a solenoid through which a current of electricity is passing possesses the properties of a steel magnet, such a solenoid will have the same inductive influence on the coil shown in Fig. 8 as the permanent magnet M there shown.

(7.) If we were to take the two solenoids mentioned in section 6 and putting one inside the other and connecting one, which we will call the secondary, to the galvanometer and the other, which we will call the primary, to our source of electricity, we will observe that every time a current is sent through the primary coil a momentary current is induced in the secondary coil, and at the instant when the current in the

primary ceases to flow a momentary current is again induced in the secondary, but in the opposite direction.

(8.) If, instead of interrupting the flow of electricity in the primary coil we simply vary its intensity we will observe inductive effects in the secondary coil each time the current in the primary is so varied.

(9.) When we briskly rub a smooth glass rod with a silk handkerchief we electrify the glass rod with a positive charge of frictional electricity. If we now bring the rod near a small pith-ball suspended by a piece of silk from a little standard we will attract the pith-ball to the rod by *induction*. The glass rod is positively charged and a negative charge is induced on the side of the pith-ball nearest the rod. Positive and negative charges of frictional electricity always possess an attraction for each other.

CHAPTER VII.

CONSERVATION OF ENERGY.

ENERGY is the power of doing work. It is present in some form throughout all nature. We cannot increase or diminish the total quantity of energy; we cannot create nor can we destroy it; we can only change its form. Energy may either be *potential* or *kinetic*; it is said to be potential when at rest and kinetic when in action. There are three forms of energy: namely, thermal, chemical and mechanical.

The potential energy in coal may, when the coal is burned, be changed into the kinetic energy of steam.

The potential energy in zinc and copper may, when immersed in dilute sulphuric acid and connected outside of the acid, be transformed into the kinetic energy of heat, gases and electricity.

The potential energy in your arm may be changed to the kinetic energy of motion when you turn the handle of a grind-stone.

The energy in coal may be changed to that of

steam; the energy in the steam may be transformed into the energy of motion; this may be transformed again into electrical energy, and this again into light, heat or power. There will not be as much energy in the electric light produced as there was in the coal, for some of the energy in the coal was lost in heat which went up the chimney instead of into the steam; some of the energy in the steam was used up on account of the friction in the engine; some of the energy in the motion of the engine escaped in the slipping of the belt and friction in the electrical machine, etc.; some of the electrical energy was lost in overcoming the resistance of the conductors leading to the electric lights, and in the lights themselves. But, if we add together the energy finally delivered in light to all the "losses" by friction, heat-waste, etc., we will have exactly the same energy as was originally in the coal. The energy in frictional heat and the heat in escaping gases is not *lost* but only becomes altered in its form. This grand principle of the saving or *conservation* of energy is what permits the universe to exist, as it has existed, for eons of ages.

PART II.—APPARATUS.

CHAPTER I.

SOURCES OF ELECTRICITY.

ELECTRICITY may be generated or developed or excited in more than one way. Its sources may be classified under five general heads called Animal, Thermal, Frictional, Chemical and Induced electricity. We can well afford to briefly consider each of these sources in their order. Many people make the mistake of thinking that there are different *kinds* of electricity, whereas electricity is always electricity, whether excited by Frictional or Chemical means or by Induction. The difference lies only in the varying effects produced by electricity generated in different ways due to such special characteristics as pressure and quantity which each may possess. It is often convenient, however, to distinguish as to the sources of electricity, as, for example, by speaking of "Animal Electricity" or "Induced Electricity."

ANIMAL ELECTRICITY.—All animal and plant

life produces electricity. In some animals, such as the electric eel, the amount is large, while in others it is very small. Some animals use their power of giving severe electric shocks as a means of defence or as a means of catching their prey. There are many curious facts known regarding animal electricity, among which is the quality possessed by any muscle of generating electricity when contracted; also, that when a muscle or nerve is injured, a current is set up between the injured and the healthy portions; also, a current can be obtained by suitably connecting the ends of a section of muscular fibres with the sides of the same. Animal electricity cannot be used to produce *X Rays*.

THERMAL ELECTRICITY.—When two unlike metals are joined at their ends and heat is applied at one of the joints, a current of electricity is generated, due to the differences in heat between the parts; such a pair of metals so connected is known as a "thermo-couple." The potential difference of a thermo-couple is very small, so generally a number of such couples are connected together to increase the total potential.

Many crystalline bodies such as a tourmaline, silicate of zinc, quartz and sulphate of quinine, when unequally heated or unequally cooled, are

oppositely electrified at opposite ends, as will be more thoroughly understood upon reading about

FRICTIONAL OR STATIC ELECTRICITY.—A charge of electricity produced by friction is peculiar, in that it resides exclusively on the surfaces of the bodies charged, as does also the charge induced in one body when brought within the influence of another statically charged body. In section 9 on page 27 you were told that the smooth glass rod when rubbed with a silk handkerchief became positively charged with electricity. You were not told, however, that at the same time the silk became negatively charged, which is true. When electricity is excited by friction two mutual and equal phases of excitement are always developed, which are called positive and negative charges. These two phases have a strong affinity for each other and are always trying to come in actual contact with and neutralize each other. When this is accomplished there is a *discharge* which leaves the electrified bodies without any charge of electricity. If the charge is sufficiently great it will not be necessary for the positive and negative surfaces to come in actual contact before there is a discharge, as the accumulated potential will force a discharge through the air from positive to negative, in the

form of a bright spark or electric flash like a lightning discharge on a small scale.

Whether a substance rubbed by another substance will be positively or negatively charged depends on the nature of the rubbing substance as well as on the nature of the substance rubbed. For instance, the following list (from "Ganot's Physics") gives a number of substances, each of which will become positively electrified when rubbed by any which follows it:

Positive.

Cat's-skin,
Glass,
Ivory,
Silk,
Rock-crystal,
The Hand,
Wood,
Sulphur,
Flannel,
Cotton,
Shellac,
Rubber,
Resin,
Guttapercha,
Metals.

Negative.

Machines have been made upon the principles suggested here, whereby powerful charges are produced by the revolution of glass disks arranged with proper rubbers, collectors and inducing strips. There are a number of these electrical machines, some strictly frictional and some so-called "influence" machines, those best known and in use being the Holtz and Wimshurst machines. Fig. 9 is an illustration of a Holtz machine as modified by Wimshurst and made by the Galvano-Faradic Company, New York City. In Chapter I. of Part III. will be found a description of how the frictional machine may be useful in producing X Ray effects.

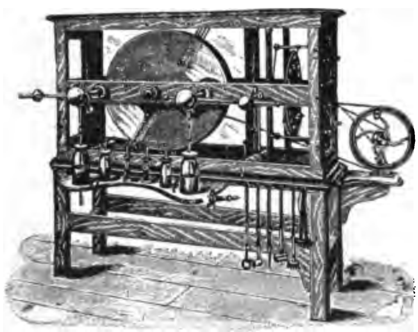

Fig. 9.

CHEMICAL ELECTRICITY.—Under this head may be grouped two very important sources of electricity, viz., *Primary* and *Secondary Batteries*, which we must now learn something about.

(1.) When plates of two different metals or one metal and one non-metallic body (such as

carbon) are placed in a liquid (called an electrolyte) and the two plates are connected together outside of the liquid a current of electricity is generated. This combination of plates and electrolyte is known as a *cell* of Primary (or Galvanic) Battery. A very simple form of primary battery is made by taking a plate of copper and one of zinc and immersing them partially in a solution of sulphuric acid and water. This constitutes the original cell of Volta. A "battery" may be made up of one "cell" or two or more "cells" connected together. A copper-zinc cell is illustrated in Fig. 10 which it would be well to study a little. When the two wires leading from the copper (c) and zinc (z) plates are connected the sulphuric acid is decomposed, forming hydrogen gas at

Fig. 10.

the copper plate and combining with the zinc to form sulphate of zinc. The electricity developed by this chemical action flows from the plate most acted on (the zinc in this case) through the liquid to the other plate (the copper), and from that through the external conductors back to the first plate again. This is indicated by the arrows in Fig. 10. It will also be noticed that the signs plus (+) and minus (—) are used. This indicates

that the portion of the zinc plate in the liquid is *positive* (+) to the portion of the copper plate in the liquid, which is therefore *negative* (—) ; also that the exposed part of the copper plate is positive to the exposed part of the zinc plate, which is therefore negative. It is the practice to call that plate *from which* the electricity flows, outside the liquid, the *positive pole*, and the plate *to which* the electricity returns, outside the liquid, the *negative pole*, and to refer to the plate within the electrolyte from which the current starts as the *positive element* and the other plate within the electrolyte as the *negative element*.

A number of different forms of primary batteries have been devised but all can be divided into two classes, namely, *open-circuit* and *closed-circuit* batteries.

The open-circuit class contains those varieties which work best when not constantly in use, on bell-circuits, hotel-calls and signal-circuits generally. The best of this class of batteries is the "Leclanché" which is very widely known and extensively used. The elements used are of zinc and carbon, placed in a solution of sal-ammoniac; the carbon is surrounded by powdered black oxide of manganese. When the Leclanché cell is made to supply electricity continuously

for any length of time it soon "runs down" and will do no more work until given a "rest," but when only used occasionally and for short periods it is very efficient and satisfactory. Fig. 11 is an illustration of a Leclanché cell. Such a cell gives a potential of about 1.47 volts.

FIG. 11.

The closed-circuit class contains those varieties which work best when in constant use or when the circuit is normally "closed." The best representative of this class is the "Gravity" battery, which is a modification of the "Daniell" battery. The Daniell cell, a sketch of which is given in Fig. 12, is made up of zinc and copper elements separated from each other by a cup of porous clay in which is put the copper plate surrounded by sulphate of copper crystals; the zinc is immersed in dilute sulphuric acid. The electromotive force is about 1.072 volts and is remarkably constant. It only differs from the original cell of Volta in the addition of a porous cup in which is placed

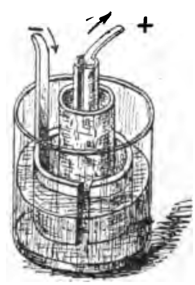

FIG. 12.

the copper element and sulphate of copper crystals. The serious disadvantage in the use of the Daniell cell is the fact that the copper formed by the chemical processes within the cell is gradually deposited in the pores of the porous cup increasing its resistance. This trouble is not met with in the Gravity cell illustrated in Fig. 13. As will be seen the copper strip is at the bottom of the jar and the zinc wheel or "crow-foot" is near the top; a sulphate of copper solution is poured over the copper and a quantity of copper crystals are also put in and on top of this solution is poured a dilute solution of sulphate of zinc. The *specific gravity* of these two solutions is so different that the heavier or sulphate of copper solution always remains at the bottom. The zinc sulphate solution as a substitute for the sulphuric acid of the Daniell's cell gives a somewhat lower voltage but makes the action of the cell even more constant.

FIG. 13.

(2.) When two plates of the same metal (usually some form of lead) are placed in a solution which normally does not attack them (usually

dilute sulphuric acid) no electrical action takes place. But if a current of electricity generated in some outside source is allowed to pass into one of the plates and then through the solution to the other plate and back to the source again, we set up a chemical action in the solution which decomposes it and causes a different deposit to be made on each of the plates. Fig. 14 shows a cell made up of two lead plates immersed in an electrolyte of sulphuric acid, into which current is flowing from an outside source. We notice in this figure the current is passing into the plate A then through the electrolyte to the plate B and out again. The chemical action spoken of above forms peroxide of lead on the plate A (chemists write peroxide of lead PbO_2) and spongy metallic lead (known by the letters Pb) on the plate B. So we see that whereas we started by forcing electricity into this cell with the plates A and B alike and incapable of themselves setting up an electrical action we now have two *different* elements (PbO_2 and Pb) in an electrolyte (H_2SO_4) capable of acting on them. In other words, a cell incapable

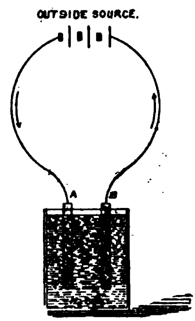

FIG. 14.

of generating electricity becomes *an active source* after electricity has once passed through it. If we now connect this cell to a small electric lamp, or other device, as in Fig. 15, a current of electricity will be generated and one atom of oxygen (O) of each molecule of the PbO_2 will be transferred from plate A to plate B and joining the Pb of plate B will form monoxide of lead, PbO, and plate A will then also have become PbO and both plates will be alike. When this is accomplished over the entire surface of the plates no more current will flow from the cell and it will be necessary to once more *charge* the cell from an outside source as before if we wish to obtain more electricity from it. The peculiarity of such a cell which requires electricity to be put into it before any can be obtained from it has caused the cell to be named a "Storage" or Secondary Battery. Although the effect we obtain is the same as if the cell was a reservoir in which we *stored* electricity until it was needed we do not *really* store it, for we have seen that what happens is *for the charging current to make a primary battery of*

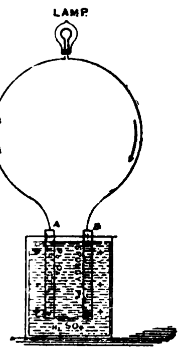

FIG. 15.

the cell by altering the nature of the elements. What we in reality "store" is chemical energy and not electricity. If we observe Fig. 14 we will see that the *charging* current is coming into the cell at the plate A and passing out at the plate B. In Fig. 15, however, we see the *discharging* current comes out at the plate A returning to the plate B. In other words, a secondary battery discharges in a direction opposite to that in which it is charged.

The potential of a cell of secondary battery is about 2 volts. In secondary batteries as in primary batteries, the potential difference of a cell does not depend on the size of the elements but on their nature and that of the electrolyte. The quantity of electricity to be obtained from a cell of any kind of battery is directly dependent upon the area of the elements exposed to the electrolyte.

INDUCED ELECTRICITY.—Sections 4 and 5 of our chapter on Induction, told that when we move a loop or coil of wire towards or away from a magnet or move the magnet towards or away from the loop or coil, momentary currents were *induced* in the coil of wire, and that these momentary currents would first go in one direction and then the other, depending on the direction

of the movement to or fro. These principles were discovered in 1831 by Michael Faraday, the noted English scientist, and upon them all mechanical generators or dynamo-electric machines of the present day are constructed. Batteries cost too much to run to permit their being largely used for electric lighting or power purposes. It costs much more to burn up zinc in a battery than it does to burn coal in a steam-boiler of the same power. There are two general classes of dynamo-electric machines named after the character of the currents delivered by each. These are (1) *alternating current* and (2) *continuous current* dynamos, and a few words may be written about each.

(1.) If we take a loop of wire and mount it on a shaft placed between the N and S poles of a magnet, as shown in Fig. 16, we have the simplest form of dynamo. Were we to connect the ends of the loop of wire to two metallic rings also mounted on the shaft we can adjust springs or brushes so as to rest on such rings, and at the same time be connected to a galvanometer. If we now turn the crank-handle in the direction indi-

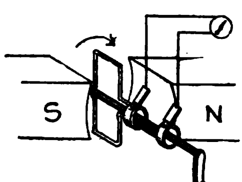

FIG. 16.

cated by the arrow, a current will be induced in the loop in one direction as it approaches the horizontal position and in the opposite direction as it approaches the vertical position. These

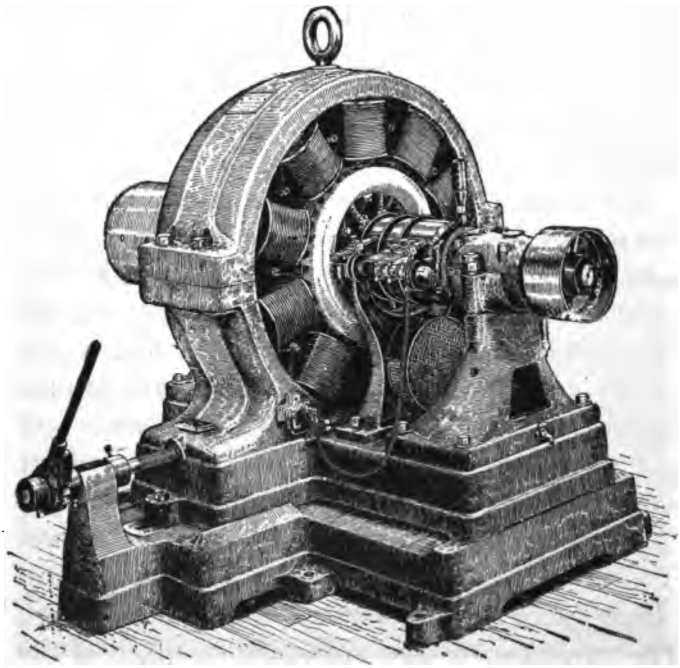

FIG. 17.

currents flow through the loop to the rings and collecting brushes or springs and thence to the galvanometer and back. Being induced first in one direction and then the other they are known

as *alternating* currents. If we use a number of loops on the revolving shaft and a number of pairs of magnet-poles instead of one we will get greater voltage when they are properly connected. Fig. 16 is a theoretical dynamo but Fig. 17 is a practical alternating current dynamo capable of supplying many hundreds of electric lights or many horse-power to electric motors.

(2.) Were we to take the simple loop of Fig. 16 and and connect its ends to the two halves of a split-tube (instead of the rings) as shown in Fig. 18 we will find a different character of current flowing to the external circuit

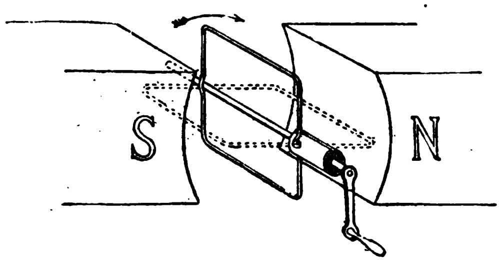

FIG. 18.

(which may include a galvanometer as before). The mere use of the split-tube in place of the two rings so alters the conditions that instead of delivering an *alternating* current to the external circuit, we deliver a *continuous* current or one which always travels in the same direction. This is because the two brushes or metal springs

resting on the split-tube (known as the "commutator") first press on one half the tube, and then the other half as the shaft revolves, so that although the alternating current is still induced in the loops it is delivered as a continuous current. This is readily seen by referring to Fig. 19 which is a section through the commutator and brushes. If the downward moving half of the loop is positive, the upward moving-half will be negative and it will be readily seen that the positive half in one position will be the negative half when it reaches another position. The brushes do not revolve but always "collect" the current at the best + and — points. Fig. 20 illustrates a modern Edison continuous current dynamo similar to those in use all over the world for lighting stores and houses.

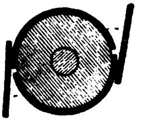

FIG. 19.

The magnets of all modern and practical dynamos are made of iron wound with wire and supplied with electricity. The reader will recognize that these are therefore not permanent magnets but electromagnets.

In closing this chapter you must be told that batteries and dynamos are alike in these respects:

(1.) If a greater potential is needed than one cell or dynamo can give, connect two or more together *in series* as shown in Fig. 21, that is, connect the + of one unit to the — of the next

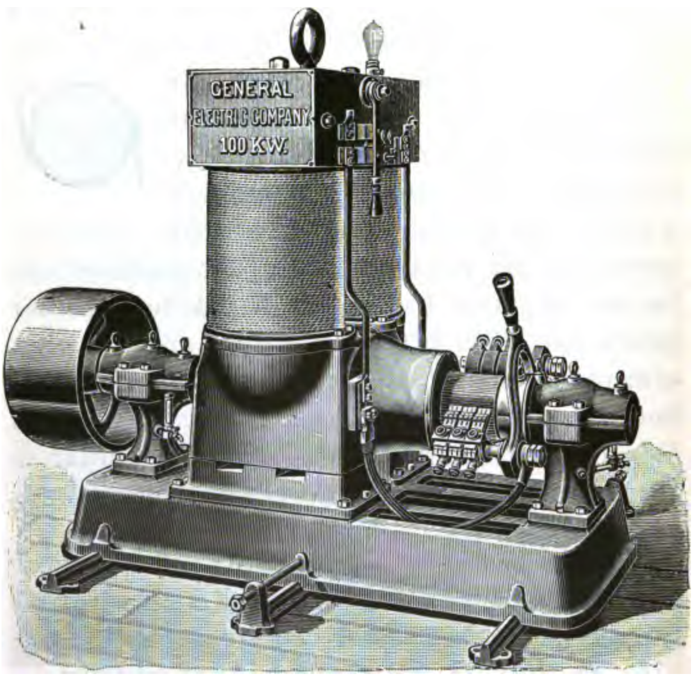

FIG. 20.

and the remaining + and — to the outside circuit. In Fig. 21 the total potential would be three times as high as if one unit was used,

but the ampères or rate of current flow will not be increased ;

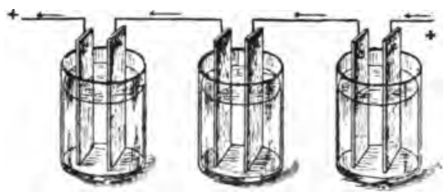

Fig. 21.

(2.) If we want a greater flow of current but at no increase of potential we connect our units in ***parallel*** or ***multiple-arc*** as shown in Fig. 22. All the + poles are connected together and all the — poles are similarly connected. Here we have the ability to obtain three times the rate of flow than if but one unit was used ;

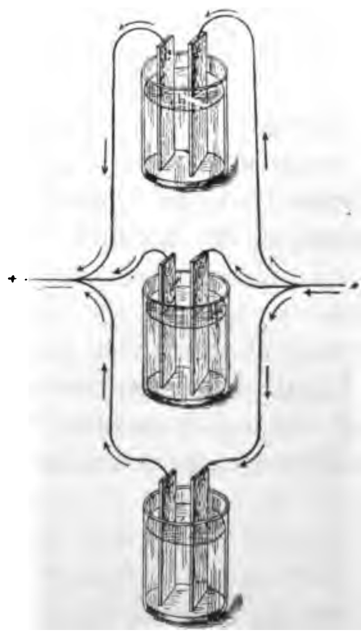

Fig. 22.

(3.) If we wish to obtain more potential and greater rate of flow at the same time (without increasing the *size* of our units) we must combine the two previous methods

in the *multiple-series* method of connection as shown in Fig 23. In this case we obtain three times the voltage and twice the ampèrage of a single unit.

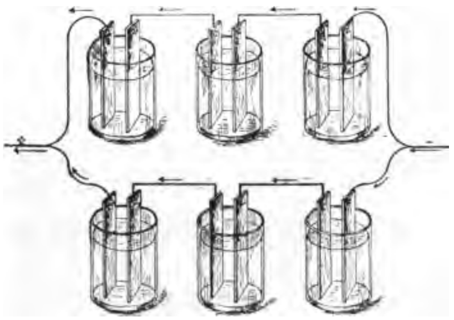

Fig. 23.

It having been shown that the pressure or ampèrage of a battery depends on the nature of its elements and electrolyte, it only remains for the reader to know that the characteristics of a dynamo depend on the size and shape of its electromagnets and the size and quantity of wire in the armature or around the magnets and also upon the speed at which the armature is made to revolve. A skilled designer can tell in advance the number of volts and ampères his dynamo will furnish under given conditions.

CHAPTER II.

THE INDUCTION COIL.

IF the reader of this little book has carefully considered what has been said up to this point, he will have acquired such a general knowledge of electrical principles that what follows will be very clear to him.

One of the most important pieces of apparatus generally used in the production of X Rays is the Induction Coil. In fact, although other apparatus can be used to perform its work, the induction coil is by far the most satisfactory to handle. The reasons for this will develop as we proceed.

You were shown in section 7 of the chapter on Induction that if a secondary coil is made to surround a primary coil which is connected to a battery or dynamo and a current is sent through the primary, that a momentary current is induced in the secondary; also, that at the instant when the current in the primary ceases to flow a momentary current is again induced in the

secondary but in the opposite direction. It will thus be seen that if we rapidly "make and break the circuit" through the primary (that is, send intermittent currents through it) we induce *alternating* currents in the secondary coil.

There is another interesting and important point to be considered: The greater the number of turns in the secondary coil, in proportion to the number of turns in the primary coil, the greater will be the potential and the smaller will be the ampèrage developed in the secondary in proportion to that in the primary. X Ray work demands exceedingly high potentials and small currents, so the primary coil is always wound with a small number of turns of coarse wire while the secondary coil is wound with an immense number of turns of very fine wire. In some induction coils, the wire in the secondary is *many miles* long. The potential given by an induction coil used for X Ray work must be so great that it will overcome the resistance of the air and give sparks of from two to twelve inches or more in length. Good work can be done with an induction coil capable of giving a two-inch spark but the greater the power of a coil the wider range of usefulness it has. In describing the induction coil and what it does, we will speak first

of the primary circuit and then of the secondary circuit and their component parts.

PRIMARY CIRCUIT.—Any electrical "circuit" means the total path travelled by the current; it includes the source, the receptive device in which useful work is performed and the conductors connecting the two, together with any switches or devices for breaking the circuit or interrupting the flow of current.

The primary circuit, therefore, of an induction coil includes the battery or dynamo as a source; the coil of coarse wire wound around a bundle of soft-iron wires or rods, the conductors connecting the coil with the battery or dynamo and the necessary circuit-breaking device; also a "condenser" connected around the circuit-breaking device to reduce the spark when the circuit is broken. We have described the various sources of electricity suitable for this use and it is desirable to now refer to Fig. 24 which is a diagram of the primary circuit and describe its features.

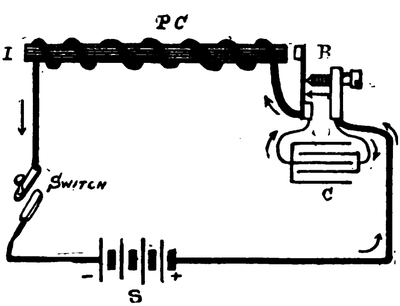

Fig. 24.

S is the source of electricity which may be either a primary battery, a secondary battery or a continuous-current dynamo-electric machine. I is a core made of a bundle of soft iron wires used to intensify the effect of the primary coil PC wound around it. Iron wire is used instead of an iron bar, because the wire can be more rapidly magnetized and demagnetized. As the voltage in the primary coil is small and the ampèrage quite large (from 5 to 20 ampères) the coil PC must be of small resistance, that is, have but a few turns of large wire. The circuit-breaker is at B and consists, as here shown, of a piece of iron to which is fastened a flat spring held firmly at one end; the end carrying the iron "head" is directly in front of the iron core and is free to vibrate. Against the side of the flat spring furtherest from the iron core presses an adjustable screw; the end of the screw and the spot it touches on the spring are both of platinum so as to be as little affected as possible by the spark caused by the heavy current jumping across the break when the spring vibrates. Of course, when the spring vibrates it flies away from the screw-tip and then flies back again, thus breaking and completing the circuit.

In order that the best inductive effects may be obtained from the primary coil it is necessary

that the *break* in the circuit should be very sudden and that there should be as little sparking as possible at the contact-breaker B. This sparking can be much reduced by connecting a "condenser" C to the spring and the contact-screw of the circuit-breaker B. This condenser acts as a temporary reservoir for the excessive current flowing when the circuit is broken and accomplishes what the springs on a carriage do, that is, deadens the effect of a sudden jar. This excessive current is due to the mutual inductive action of each loop of the primary coil upon every other loop. The same induction takes place when the circuit is made as when it is broken, but the presence of the condenser causes it to take a longer time to "load up" than to "unload." In Chapter V. of Part I. we learned that when we force electricity into a conductor we charge it with a certain potential dependent upon its *capacity* in *microfarads*. The condenser in Fig. 24 is the conductor so charged and its effectiveness depends on its *capacity*. A condenser is usually made of sheets of tinfoil carefully separated or *insulated* by sheets of paraffined paper, oiled silk or mica, the alternate sheets of tinfoil being connected *in multiple* as indicated by C in Fig. 24.

The action of the various parts illustrated in Fig. 24 is as follows: When the switch Sw is closed the electricity flows from the source S to the circuit-breaker B, then through the primary coil PC and back to S. When the current passes through PC it makes a magnet of the iron core I which attracts the iron head on the spring of B making a break in the circuit between the spring and the contact-screw. There is a spark at this point which is minimized by the action of the condenser C in receiving the "blow." When the circuit is broken by the attraction of the spring away from the contact-screw the iron core I loses its magnetism because no current is flowing around it, so the iron head on the spring is no longer attracted and flies back against the contact screw. The instant the screw is touched the electricity again flows through the coil PC and the magnet I again acts, so that so long as the switch Sw is closed there will be a rapid vibration of the circuit-breaker B and, consequently, a rapid making and breaking of the circuit through the coil PC.

An alternating-current dynamo may be used as a source without a circuit-breaker but it is not nearly so effective for X Ray work because the alternating current is not a current which flows

at full strength for an instant in one direction and then suddenly turns around and flows at full strength in the opposite direction. As a matter of fact the alternating current starts at zero or no potential and gradually rises to full potential in one direction, then gradually falls to zero, then rises gradually again to full potential in the opposite direction and then falls to zero again only to rise again as at first. This can be illustrated by a diagram as in Fig. 25, where the line OO is the zero line or line of no potential. The potential starts to rise at A in a positive direction of flow until it reaches its maximum at B, after which it falls to C and then changes its direction to the opposite of the first until it reaches a negative maximum at D, after which it falls to E to rise in a positive direction again.

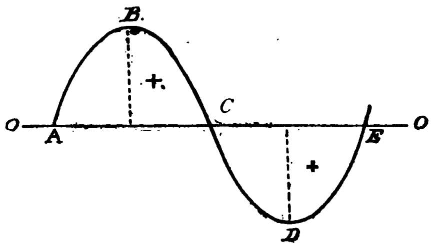

Fig. 25.

To obtain first class X Ray results with an induction coil it is absolutely necessary that the inducing currents should be short, sharp, snappy and vigorous.

When very large induction coils are used, requiring heavy primary currents, that is, a large number of ampères, it is desirable to use a different form of circuit breaker than the one shown at B in Fig. 24. The best breaker for the purpose is a *wheel* such as is shown in Fig. 26. It should be made of brass with pieces of slate carefully fitted into its circumference, so that when the wheel is made to revolve by an electric motor or other motive-power the fixed brush A will first rest on a brass projection and then on the exposed section of the *insulating slate*. The fixed brush B always makes contact on the hub of the wheel. The slate, being of the form shown and carefully fitted, will wear indefinitely and cannot fly out. The "makes" are a trifle longer than the "breaks," or, in other words, the exposed sections of brass are a little longer than the exposed sections of slate.

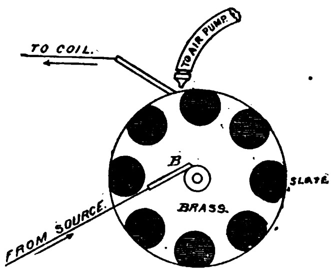

Fig. 26.

With such large primary currents it is not only necessary to connect a condenser around the break-wheel, as was done with the circuit-breaker B in Fig. 24, but it is also desirable to have an

air-blast directed at the sparking-point on the wheel so as to keep down the spark as shown at C in Fig. 26. This break wheel was one of many results of a long course of experimentation leading to the X Ray work presented in this book and is likely to become a standard article. In its present form it was invented and is now made by Mr. H. E. Vineing, Master Electrician, Brooklyn Navy Yard. It is especially valuable in connection with the production of X Rays, because the smaller or "cleaner" the spark at the circuit-breaker in the primary circuit the finer will be the effects produced.

SECONDARY CIRCUIT.—As compared with the primary circuit the secondary circuit is very simple. It comprises the secondary coil SC of Fig. 27 (placed over the primary coil PC of Fig. 24), the terminals T1 and T2, which are adjustable so as to regulate the gap-space A, and the Crookes tube in which are developed the X Rays.

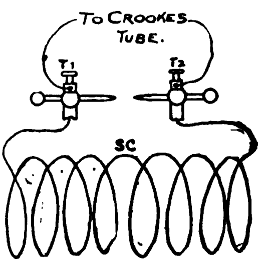

Fig. 27.

This tube will be described in the next chapter.

As has been stated before, the potential from the secondary is necessarily enormous. You can

imagine how great when to obtain a six-inch spark from Daniell's batteries instead of an induction coil about 600,000 cells would be required. The ampères necessary are, however, very small indeed, so the secondary coil is wound with a great length and very many turns of very fine wire.

If Fig. 27 is now placed over Fig. 24 Fig. 28, which is a diagram of a complete induction coil is obtained. The rapid vibration of the circuit-breaker B causes intermittent currents to pass through the primary coil PC, as already described. These intermittent primary currents induce alternating currents of high potential in the secondary coil SC, and if the terminals T_1 and T_2 are brought the proper distance apart, a brilliant, thin, snappy spark will pass from the one to the other. If the terminals are separated so the spark will not jump the gap, the induced

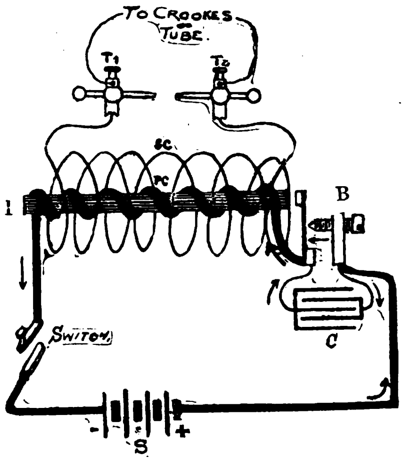

FIG. 28.

current will be available in the Crookes tube for the production of X Rays.

It has been stated that there is an "excessive" current in the primary coil upon the breaking of the circuit. The induced electro-motive forces in the secondary coil last longer, but are feebler at "make" than at "break," and *are not strong enough to send sparks.* Therefore, although the currents induced in the secondary are alternating currents, there is a greater impulse in one direction than the other, or the current in one direction preponderates over that in the other direction and we have a preponderating positive or *anode* terminal and a preponderating negative or *cathode* terminal even though each terminal is alternately anode and cathode. When the cathode of an induction coil is spoken of a preponderating cathode is meant.

CHAPTER III.

CROOKES TUBES AND THEIR VARIETIES.

THE Crookes tube was named from Prof. William Crookes, who studied the phenomena of electrical discharge in tubes whose vacua were high as compared with Geissler tubes whose vacua are low. Both the Crookes and Geissler tubes are glass bulbs or tubes of varying shapes, from which the contained air or gases have been extracted by proper pumps. In this manner a vacuum has been created. By a high vacuum is meant that only about a millionth part of the air originally in the tube remains, while in a low vacuum about one-thousandth part may remain. Familiar examples of low vacuum tubes are Geissler tubes and incandescent electric lamps.

Further essentials of Geissler or Crookes tubes are the wires which pass through the glass and which are known as electrodes. One of these is commonly made a positive pole and the other a negative pole, or, as pointed out in the chapter on the Induction Coil, an *anode* and a *cathode*.

The shape of the electrode after it has entered the tube or bulb is capable of great variety. It may be a simple straight wire, a flat disk, or, as in the most recently approved forms of Crookes tubes for X Ray purposes, a metallic cup whose function it is to concentrate or focus the stream from the cathode to a converging point within the bulb and upon a flat disk of metal which may or may not be the anode. The electrodes where they enter the glass and are fused to it are necessarily of platinum, owing to the fact that the rate of expansion of glass and of platinum, when subjected to alterations of temperature, is practically the same. From the point of fusion inwards, however, the electrode may be of any conducting material, metallic or otherwise, which can be mechanically and electrically united to the platinum. Aluminum has been found to be the best material for those portions of the electrode within the bulb.

FIG. 29.

There is hardly a limit to the possible variations in the shape of the bulb of a Crookes tube or the shape or position of the electrodes, but there are certain forms which have

been most used by experimenters, and these will now be described.

Fig. 29 represents a common form of the globular Crookes tube having a disk of aluminum as a cathode and three straight platinum wires, any one or all of which may be used as the anode.

Fig. 30 represents the familiar pear-shaped Crookes tube having two electrode disks of aluminum, the one in the end to be used as the cathode and the lower one the anode.

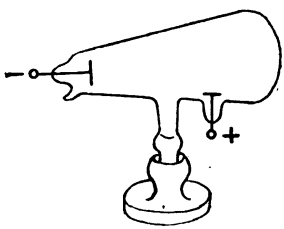

FIG. 30.

Figure 31 is an illustration of a tube devised by Prof. Crookes to demonstrate that radiant matter when intercepted by a solid body casts a shadow. This is a piece of apparatus which was found in almost all college laboratories at the time Prof. Roentgen first announced his wonderful discovery, and most of the early experiments with X Rays were made with the aid of these

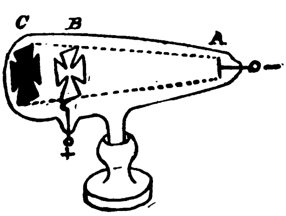

Fig. 31.

tubes. It is pear-shaped and the negative pole is at the pointed end. Beyond its middle is mounted on a hinge a piece of aluminum, B, cut in the shape of a maltese cross. The cathodic stream coming from the negative pole A is partially intercepted by the aluminum cross and produces an image of it on the end of the tube as represented at C. This image is due to the fact that the cathode rays when they strike the glass at the bulbous end produce fluorescence of the glass at all points where they have escaped the intercepting cross.

Owing to the fact that the cross is hinged a slight movement of the tube causes it to take a horizontal position and the same stream is now projected against the entire larger end of the tube, causing a general fluorescence. It may be mentioned here that it was from this fluorescent end that Roentgen conceived his X Ray to emanate. The pear-shaped tube shown in Fig. 30 did much of the early work in taking Roentgen pictures. The above references to "cathodic streams" and "radiant matter" will be better understood after reading the chapter on the Nature of the X Ray in Part III.

Fig. 32 represents a form of Crookes tube of considerable interest since it is the prototype of

the tubes now most in use to produce the X Ray. The cathode A is cup-shaped and focuses a cathodic stream upon a piece of platinum B supported in the centre of the bulb. At C is another entering electrode and either B or C may be used as the anode. This is essentially the focus or reflector type of tube which has superseded the globular and pear-shaped tubes and which is now generally in use. The only essential difference is that the anode B may be bent one way or the other to a greater or less extent.

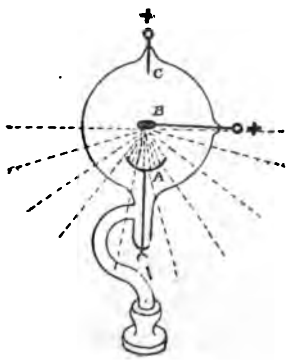

Fig. 32.

Fig. 33 represents a focusing tube as it was first introduced into this country from London. In this shape it was first proposed by Mr. Herbert Jackson, of King's College, London, and first shown in public by Alfred W. Porter, B. Sc., of University College, London. It was first used in this country by

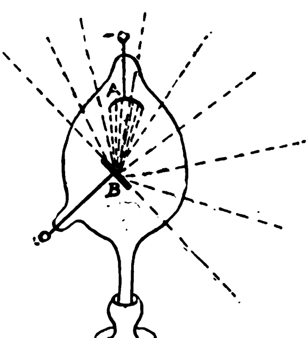

Fig. 33.

Dr. Morton. It will be noted that in this form of tube the reflecting disk B serves both as anode and reflector and as a probable source of the X Rays. This tube represents the final type of successful tube up to the present writing.

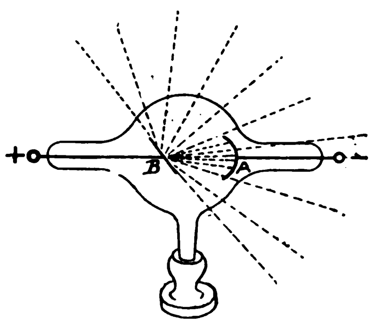

Fig. 34.

Fig. 34 shows a modification of this type found desirable to keep pace with advancing X Ray work. In Fig. 33 the distance between the external electrodes is but 4 inches while in Fig. 34 this distance has been increased to 10 inches. The advantage of Fig. 34 over Fig. 33 is that the greater the distance between the external electrodes the greater is the potential which can be utilized for the production of X Rays without the spark jumping around the outside of the bulb.

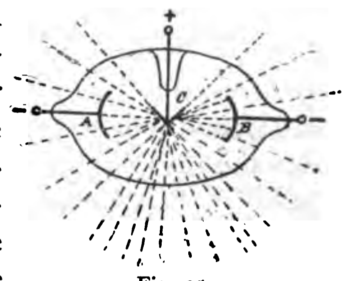

Fig. 35.

Prof. Elihu Thomson has proposed as a stand-

ard tube a further modification of the reflecting tube shown in Fig. 35. The two focusing cups A and B may constitute the two electrodes, or A and B may be united to form one cathode and the V-shaped piece of platinum C may then be the anode. The former connections ought to be employed in case alternating or oscillatory currents are used; the latter connections when the induction-coil alone is used.

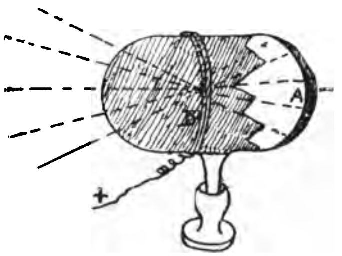

Fig. 36.

Fig. 36 is a Morton vacuum bulb fitted with external electrodes of aluminum foil devised in the first instance for use with a Holtz or other influence machine but equally useful in connection with an induction coil. The small aluminum cap A is cathodic and concentrates the rays on the opposite end of the bulb. The anode B is a cup of aluminum foil covering a large proportion of the bulb as shown in the sketch. The innovation in this form of bulb or tube lies in the fact that the cathodic stream, as it impinges on the anode, apparently proceeds on its way in the form of X Rays; therefore this type is not a "reflecting" tube. A full description

of this tube was given in the *Electrical Engineer* of April 8th, 1896, page 355, where it was said: "It will be noticed there is no window or opening in the anode. Should a window be cut in the anodic metal with the hope of getting a better effect upon the sensitized plate the efficacy of the bulb will be greatly diminished. This bulb works well with a static machine (or with an induction coil) and it may prove of interest to many who own such machines to construct their own X Ray bulbs."

This idea of a coincident X Ray and cathodic stream as applied to a tube having external electrodes has been modified by the originator of the above as illustrated in Fig. 37. The focusing cathodic cup A is of aluminum, and the thin disk or button B is of carbon and is held firmly in its position by the anode connection passing through the glass. It will be seen that though the form of this tube is similar to Crookes tube shown in Fig. 32, the X Rays appear to pass *through* the anode instead of being reflected from it.

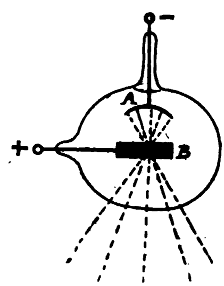

FIG. 37.

Fig. 38.

The Tesla tube is shown in Fig. 38. It has been devised by him for use with the extremely high potential and high frequency currents with which his name is so prominently identified. But one terminal is needed in this form of tube which can only be used with a powerful Tesla coil.

Another ingenious tube is that devised by Mr. Edison. The latest form of this tube is shown in Fig. 39 where two slanting plate or disk electrodes mutually converge the cathodic stream to a concentrated area of the glass surface. As the stream strikes the glass at an angle, overheating is, to a great extent, avoided.

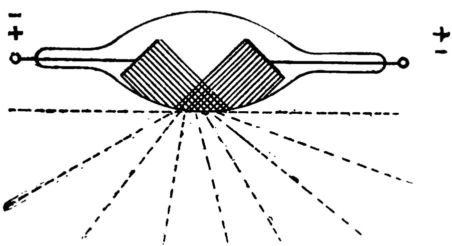

FIG. 39.

On the whole we would advise the intending investigator to purchase a reflecting or focus tube.

CHAPTER IV.

THE FLUOROSCOPE.

PROFESSOR ROENTGEN'S first announcement made public the fact that fluorescent substances were excited by the X Ray. This indeed, was an observation which fixed his attention upon the new phenomena. Salvioni, acting upon this statement of Roentgen, devised the *cryptoscope* which was simply a tube having at one end a pasteboard cover coated with fine crystals of platino-cyanide of barium (mentioned by Roentgen) and at the other an eye-piece through which to view the shadow cast upon the fluorescent screen by the intervention of the opaque object between it and the Crookes tube.

When Mr. Edison took up X Ray work, and developed a practical device which he has named the *fluoroscope*, he contributed to the art one of the greatest of aids; it is the guide and friend of every X Ray operator. Its invention consisted in adopting a screen of considerable size, in selecting a new substance (namely, tungstate

of calcium) which exceeded in fluorescent qualities the platino-cyanide of barium and in adopting a large camera or dark-chamber fashioned in stereopticon form to admit of the use of both eyes at once at a distance from the screen convenient to the eyesight. Mr. Edison is said to have investigated over 1800 different substances before adopting the tungstate of calcium.

The fluoroscope enables the experimenter to determine whether X Rays are being produced or not in the Crookes tube, and if produced, it enables him to decide upon their degree of intensity.

In all practical work with the X Ray, it is necessary to have a standard of intensity which will serve as a guide both as to when to work and how long. This standard will have to be set by each operator for himself. For instance, he will soon learn to recognize a standard clearness and brilliancy of the picture of the bones of his own hand or forearm, as the case may be.

It will be found in the chapter on the Nature of the X Ray that some substances are more penetrable by X Rays than others. Thus, aluminum is more penetrable (or transparent) than platinum, and flesh more so than bone. Therefore, if X Rays are directed upon a fluorescent

screen, illuminating its surface evenly, and being between the screen and the Crookes tube an opaque or semi-opaque substance, two things happen: first, some of the X Rays are intercepted by the substance, and second, those portions of the screen not receiving the full number of X Rays do not fluoresce to such a high degree. The effect of this is the same as if the intervention of the substance between the Crookes tube, and the screen cast a *shadow* on the screen. We therefore actually see not the opaque object itself but its shadow as in the case of light. When the object is close to the screen the shadow is life-size and most clearly defined, while if removed to some distance from the screen, the shadow is increased in size and loses in distinctness. It is for this reason that some of the bones of the human body which cannot by reason of their anatomical situation be brought close to the screen or sensitive plate cannot be distinctly seen in the fluoroscope or outlined with great clearness on the sensitive plate when photographed. To a great extent this defect both in fluoroscopy and photography can be obviated by removing the Crookes tube to a greater distance from the screen or plate. There are limitations to this, however, as the in-

tensity of the X Ray diminishes inversely as the square of the distance. Therefore to obtain good results at these increased distances requires increased power in the Crookes tube itself.

The fluoroscope is already an invaluable aid in surgical diagnosis. Foreign bodies, such as bullets, needles, etc., may be located in the flesh, fractures may be discovered, or distinguished from dislocations and the organs of the body,

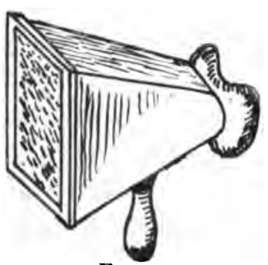

FIG. 40.

like the heart, liver and spleen, may be outlined. Of this more will be said in detail later on. A sketch of the Edison fluoroscòpe is shown in Fig. 40. This instrument is manufactured by Messrs. Aylesworth & Jackson, Orange, N. J.

CHAPTER V.

PHOTOGRAPHIC APPARATUS.

MANY people call this the "Electrical Age." It is. It might also be called the "Photographic Age." The number of people who own photographic cameras is enormous; the number who expect to some day own such apparatus is still greater. It is a difficult matter to meet a person who has not done more or less with photography and who has not quite decided views as to which is the best camera and which the best developer! In fact, the wide-spread knowledge of photography is, in a large degree, responsible for the universal interest and curiosity concerning the X Ray. The photographer has become so accustomed to consider "light" to be an absolute requirement in his work that he is impressed at once by the *unnatural* process of taking pictures in the dark and of that which he cannot see. He was at first so convinced that it was impossible to see through a pine board or a man's body that he was inclined to believe the whole X Ray excitement to be the

product of the imagination. Like all who doubt he must see to believe. But when once he has seen, he is naturally inclined to ascribe to the new agency powers which it does not possess. It will be our effort to point out the limitations as well as the astonishing capabilities of the new discovery.

Another photographic idol will be shattered when it is found that in the "photography of the invisible" *no camera* is needed. How this simplifies matters! Only a sensitive plate, which can be bought of any dealer, and a suitable holder for the same are required. If you have no camera and no dark-room, no developing utensils and no knowledge as to the development of negatives, you may still take X Ray pictures. If you have a camera and all the necessaries of dark-room equipment you may use them, but *a camera cannot be used except to photograph the shadow image cast by the X Ray upon a fluorescent screen.* More will be said about this process in Chapter VI. of Part III., but there are a few points connected with photography which will be considered here.

All X Ray pictures, whether taken with or without a camera or only seen on the luminous screen of a fluoroscope, are not pictures of

surfaces, but are, in reality, as has been said, *shadow* pictures. The X Ray penetrates some substances more readily than others, just as clear glass is more transparent than paper to sunlight. It is odd, however, that some of the substances most easily penetrated by the X Ray are very opaque to ordinary light. Prof. Roentgen showed in his original announcement (see appendix) that aluminum is about 200 times more transparent than platinum to the X Ray, yet both metals are opaque to sunlight. The X Ray will penetrate flesh and bone, but will penetrate flesh much more readily than bone. Therefore, if the hand is placed between the fluoroscope and the Crookes tube and the X Ray is projected through the hand, it will be seen by the fluoroscope that the bones cast more of a shadow than the transparent flesh and stand out in bold relief.

It will be interesting to note that carbon in any form—as diamond or as coal or graphite—is almost perfectly transparent to the X Ray, while lead is almost totally impenetrable by it.

While the X Ray has been reflected to a slight degree by Prof. O. W. Rood, and also by Mr. Nikola Tesla in the course of some brilliant experiments, it has not been found on the whole to

obey the usual law of reflection as applied to light.

The X Ray possesses another remarkable property, very interesting to the student of photography. It has not yet been found possible to *refract* it. You will remember that refraction is the bending of a ray of ordinary light out of its course when passing from one medium to another of different density. Thus when light rays pass from air into glass (at an angle other than a right angle to the surface of the glass) they are refracted or bent from their course; they are bent once more when they pass again from the glass to the air. The rays of light coming from the candle A, to the right of Fig. 41, pass through the glass lens B, and are so refracted that if a screen was placed at C an inverted and smaller image of the candle would be thrown upon it. If, however, we were to put a Crookes tube in which X Rays were being developed at A, we would find that instead of being refracted by the lens the X Rays would pass straight through the glass notwithstanding its lens shape. It will thus be understood why a camera is useless in taking

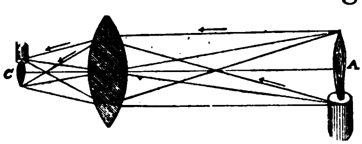

FIG. 41.

X Ray pictures except when they are thrown upon a fluorescent screen. When this is done the photographic action is produced, not by X Rays, but by ordinary light rays given off by the fluorescing crystals on the screen.

A great deal of experimental work has been done by Mr. Edison and others to determine as to which was best to use, a " quick " photographic plate or a " slow " one, that is, a plate very sensitive to light effects or one not so sensitive. The results of these numerous experiments seem to indicate what may appear strange, namely, that an impression can be made upon a " slow " plate by X Rays in the same time as upon a " quick " plate, and that a " slow " plate may be really preferable as there is less danger of its fogging. Either may be used. The reason for this is apparently that it is not so much a question of length of exposure as of quality of the X Ray being developed. As time goes on and operators become more skillful in the handling of their apparatus, X Ray photography more and more nearly approaches instantaneousness.

In closing this chapter the reader is referred to the chapter on Photographic Notes in the next Part of this book for practical suggestions as to the development of plates and other matters

of kindred interest. If you know nothing of photography that should not discourage you from experimenting with the X Ray as the processes are easily learned. The amateur can, if he so wishes, have his exposed plates developed by a photographic supply man. If it is desired to purchase cameras, or any other photographic apparatus for use in connection with X Ray work, the best plan is to go direct to a dealer in these supplies and ask his advice. If you wish to fit up a dark-room the dealer can inform you as to just what is needed in the way of lanterns, colored glass, trays, graduates, chemicals, etc. He can also give good advice as to the use of a camera and the making of "prints" after the negative has been developed.

PART III.—OPERATION.

CHAPTER I.

THE CHOICE OF APPARATUS AND HOW TO MAKE PROPER CONNECTIONS.

One of the greatest difficulties which will present itself to the experimenter is the choice of proper apparatus for the production of X Ray effects. It must be confessed that pioneers in this field of research have made none too explicit statements as to their precise methods of operation.

Roughly speaking, there may be said to be three general methods of operation, involving the use of (1) influence or static electrical machines; (2) induction-coils whose primary circuits are supplied either with continuous or alternating electrical currents; (3) Tesla transformers utilizing oscillatory electrical currents.

(1.) STATIC MACHINES.—If the experimenter has at his disposal a static machine and a Crookes tube, it is only a question as to how to combine them to produce the desired effects.

The first thing to do is to find which of the prime conductors of the static machine is positive and which is negative. As will be seen from an inspection of the Holtz machine illustrated in Fig. 9 there are sets of "combs" or "collectors" on each side of the revolving glass disks. If we operate the machine in the dark we will notice that at those combs opposite one of the prime conductors there will be a brilliant "brush light" discharge extending from the combs along the surface of the glass. This "brush" discharge is positive and is very different from the discharge at the negative combs which appears in the form of bright star-like points of light. That prime conductor which is an extension of the positive combs will be, by induction, a negative pole; in like manner the other prime conductor will be, by induction, a positive pole.

When these polarities have been determined it becomes necessary to connect to each prime conductor a small condenser in the form of a "Leyden Jar" which is a glass bottle or jar partially covered, inside and outside, with tinfoil.

Fig. 42 is an illustration of a conventional form of the Leyden jar. A brass-rod is passed through a cork in the mouth of the jar; at that end of the rod inside the jar is fastened a light chain which is permitted to come in contact with the inside coating of tinfoil while the external end of the rod is usually terminated with a brass ball. The outside tinfoil coating is usually termed the "external armature" and the inside tinfoil coating is termed the "internal armature" of the Leyden jar.

FIG. 42.

There being great danger that the discharge from large Leyden jars will crack the glass of the Crookes tube, it is desirable that the Leyden jars used in this connection should be of such a small size that there will not be more than about 10 square inches of surface in either the external or internal armatures. However, the size of the Leyden jars employed will be governed, more or less, by the degree of vacuum in the Crookes tube. The higher the vacuum the larger must

be the Leyden jars. As a rule it will be found that the small jars are all-sufficient.

In connecting the Leyden jars to the prime conductors the connection should be to the internal armatures, the external armatures being connected to the Crookes tube.

The positive prime conductor as previously determined, being connected to the internal armature of one Leyden jar will induce a negative charge in the external armature of the jar. This thus becomes a negative pole or, as generally called, the cathode, to which we must look as a source of our cathodic stream and hence of our X Ray. The external armature of the other jar receives a positive charge and is therefore the anode.

The connections we have here described will be found illustrated in Fig. 43.

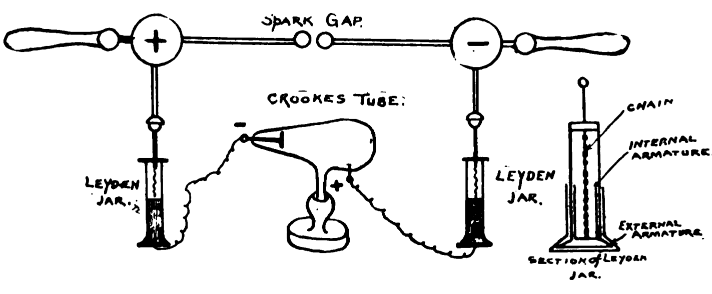

FIG. 43.

Upon starting up the static machine we will find that the spark-gap between the discharging rods is the key to the successful excitation of the Crookes tube. The length of spark passing between the discharging rods which we may use depends upon the size of our Leyden jars. If these are of the small size we have advised the length of spark will be from $\frac{1}{2}$ inches to 3 inches in length. On those occasions when the vacuum in the Crookes tube becomes higher the spark gap may be lengthened to 4 or 5 inches. In regulating the length of spark gap the experimenter must be guided very largely by experience. Since both the noise and the light from the snapping spark are exceedingly annoying it is a good plan to enclose the spark gap in a cylindrical drum of ebonite or hard-rubber having closed ends. This arrangement is very simple and the relief it affords to eye, ear and brain will be appreciated after trial. Fig. 44 shows the general arrangement of parts, the dotted lines being the portions of the discharging rods inside the cylinder.

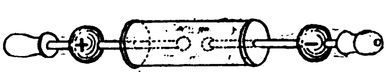

FIG. 44.

It may be mentioned that the Leyden jars may

be omitted provided the spark gap is put in *series* with the Crookes tube, but the jars increase the condenser action of the prime conductors and better effects are produced by their use.[1]

(2.) INDUCTION COIL.—Although, as has been shown above, the static machine may be used for the production of X Ray effects, the induction coil is by far the most convenient form of apparatus for this purpose. By its use more powerful X Ray effects are obtained and the time of exposure lessened.

The first thing the reader will want to know is the size of induction coil he will be called upon to purchase if he wishes to experiment. As regards this point he must be guided by the nature of the work he wishes to accomplish. If he is content with pictures of metallic objects laid upon a plate-holder, of coins within a purse, or even with pictures of the hand (where a long exposure would not be an objection) a coil capable of giving a spark 2 inches in length will suffice. If, however, it is desired to obtain successful pictures of the hands, arms, feet and lower portions of the legs, a coil having a 4-inch spark-

[1] The connections here shown for the production of "static induced currents" by the use of a spark gap and Leyden jars were described and published by Dr. Morton in 1880 and 1891; also in Transactions of American Institute of Electrical Engineers, November, 1893, page 604.

length will be required. If, finally, he wishes to take a picture of the shoulder, chest, abdomen, hips or thighs, it is essential that he have a coil with a spark-length of 8 or 10 inches. As a summary of these remarks it may be said that for reasons which will presently appear in relation to the treatment of the Crookes tube a coil giving an 8-inch spark will be found to answer all purposes above enumerated.

This coil is a fundamental piece of apparatus, but there are a number of accessories which must now be considered, as necessary for an induction coil outfit. It must be decided whether direct or alternating current sources shall be selected for the primary circuit. An opinion has already been expressed that the alternating current was not so effective as direct current when derived from a dynamo machine, but when batteries are used the chief inconvenience in altering the direction of the primary current is the necessary use of a double break-wheel. It is therefore advised that the direct current be used in the primary circuit, interrupted either by a vibrator (see Fig. 28) or by a break-wheel (see Fig. 26). Here also a choice must be made, namely, between the vibrator or break-wheel. Both mechanisms work satisfactorily, but each has its own field of usefulness.

The choice is really dependent upon the voltage available for our primary circuit.

If the Edison current (supplied by a dynamo at about 110 volts) be used with a vibrator its platinum contact points will speedily be ruined. This will not happen if the source is a battery of a few primary or storage cells, as then the voltage is quite low. But batteries are expensive and take up much room and need constant recharging or refilling.

On the other hand, if a dynamo current is used we require a break-wheel and blower run by electric or other motor, but escape all trouble from the batteries. The break-wheel is a necessity when high voltages are used, as it is useless to try to escape the destroying action of the dynamo current by cutting down its pressure with resistances. There is no question but that batteries and vibrators can and will be extensively used, but the advantages in the use of dynamo current are so great that its use is advised when it can be conveniently obtained. The kind of vibrator to use may safely be left with the instrument-maker, but the best form of break-wheel has already been described. Not less essential than the use of a break-wheel with high voltages, is the use of a blower

whose purpose it is to blow a stream of air at the spark which takes place on the break-wheel when the circuit is broken. By many the condenser is considered amply sufficient to cut down the sparking, and there is no doubt that the spark will be materially reduced especially if a condenser is used whose capacity may be regulated at will. Sufficient condenser capacity should be employed to practically "kill" the sparking at the break-wheel; the operator can readily determine how much to use when he has a regular variable condenser to control by watching the spark. On the whole, basing the opinion on practical experience, it is almost impossible to get along without a blower when dynamo currents are used. To demonstrate this in practical working, if the supply of air is temporarily cut off from the break-wheel, these things will occur: (1) A considerable lengthening of the spark on the break-wheel will appear; (2) a spark previously just able to pass between the discharging rods on the induction-coil will cease to pass; (3) the vacuum tube heats up more rapidly; and (4) the most important of all, the actual production of X Rays in the Crookes tube notably diminishes. It would appear, therefore, that both a condenser and a blower should be used to

produce the best X Ray work with high voltage current in the primary.

The only other necessary apparatus required in this connection are the proper rheostats to govern the current respectively supplied to the primary of the induction-coil, the motor which drives the break-wheel and the motor which drives the blower.

Fig. 54 (with Plates at end of book) is a photographic half-tone reproduction representing the apparatus above described as arranged for the actual taking of an X Ray picture. The devices here shown are now being assembled into more compact form for greater convenience and portability. The connections between the different devices will be readily seen from an examination of the diagram given in Fig. 45.

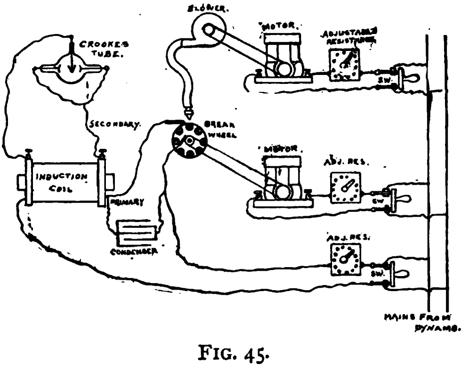

FIG. 45.

It only remains to be said that the break-wheel in the combination of apparatus here described, has 8 breaks, and is made to revolve 6,000 times per minute, so there are 48,000 makes and breaks each minute.

(3.) TESLA TRANSFORMERS.—While the early and beautiful work of Professor Roentgen and his German collaborators was performed with very simple apparatus, namely, the induction-coil, nevertheless, as interest in his discovery increased, additional means for exciting Crookes tubes were brought to public notice. Among these the one of most importance was the use of the Tesla high-potential, high-frequency currents. Mr. Tesla has himself demonstrated how by these means an X Ray of extraordinary power may be produced, even to the extent of affecting a photographic plate at a distance of forty feet. These effects were produced by apparatus on a large scale, but modifications have been made which permit the amateur to avail himself of a Tesla outfit.

Essential to the outfit is the Tesla transformer. This, in brief, consists of an induction-coil having but a few widely separated or well-insulated turns of primary wire and a comparatively few number of turns of highly insulated

secondary wire. The ratio of secondary turns to primary turns may be 24 to 1, and the insulation used is generally oil. A cut of a Tesla coil is shown in Fig. 46 connected through Leyden jars to an induction-coil.

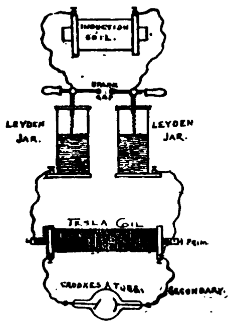

FIG. 46.

The distinctive peculiarity of the Tesla coil is the fact that its heavy primary serves as a pathway for the successive discharges of the Leyden jars, governed by a spark gap. The discharges are oscillatory in nature and the current is therefore alternating and of high frequency of alternation—much higher than is possible to obtain from any construction of dynamo machine. Fig. 46 shows the Leyden jars to be charged from the secondary terminals of an ordinary induction coil, but they may also be charged in other ways. This may be done either by a static machine or by connection with the ordinary transformer giving 52 or 104 volts when used on the street alternating current electric lighting system.

To use the Tesla transformer with a static machine, it is only necessary to connect its primary to the external armatures of Leyden

jars as shown in Fig. 47. The jars used in this case may be of the largest size, as there is by this arrangement no danger of breaking the Crookes tube. In this case also, a long spark-gap and a powerful spark may be used. Indeed, with a proper Tesla coil this method should be an excellent means for exciting the Crookes tube for the production of the X Ray.

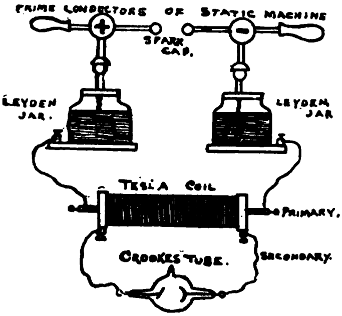

FIG. 47.

When current from the street mains is used, the same connections as shown in Fig. 46 will suffice with the exception that the street-current transformer takes the place of the ordinary induction-coil.

CHAPTER II.

ON THE NATURE OF THE X RAY.

THE letter X, it is of course well understood, is used in algebra to represent an unknown quantity. For this reason Prof. Roentgen modestly termed that special form of radiation from a Crookes tube noted by himself the X or *unknown* Ray.

As there are several terms which have not yet been explained, and as an appreciation of them is a matter of necessity in a study of this subject, we will go back of Prof. Roentgen and indicate in a general way some of the steps which lead up to his discovery.

Faraday invented the terms *anode* and *cathode* to indicate the conductor-terminals by which a current enters and leaves an electrolytic cell, which is a cell in which chemical changes in the liquid used are produced by the passage of an electric current through it. By anode he referred to the element from which the current

passed into the electrolyte, and by cathode he referred to the element to which the current passed from the electrolyte. He also studied the effects of electric discharges within rarefied gases and expanded the application of the above terms by calling the terminal from which the current passed into the vessels or tube containing the rarefied gases the anode and the terminal to which the current passed from the tube the cathode.

After Faraday came Geissler, who improved the tubes containing the rarefied gases, sealed in permanent platinum electrodes, increased the degree of rarefaction of the gases and experimented with many different gases in his tubes. The world was thus made familiar with the beautiful effects from the Geissler tubes now so well known.

It was quickly noted that the gases behaved differently at the anode and the cathode. At the cathode appeared a beautiful bluish light while the balance of the tube including the space about the anode presents a general and diffusive glow. One of the most beautiful effects produced in Geissler tubes was that of fluorescence or phosphorescence, and this, it was noted, was to be traced to the effect of the cathode. It was

even further noticed that the influence from the cathode moved in straight lines and thus the term *cathodic rays* was introduced and the cathode became a central point of interest.

The next great advance in the study of the cathode in rarefied gases comes from the brilliant researches of Prof. William Crookes, who in 1879 and subsequently, published a series of remarkable papers upon Radiant, or, as he preferred to call it, a Fourth State of Matter.

As is well known, matter is commonly supposed to exist in a solid, liquid and gaseous state. Faraday, it is true, had already suggested a fourth or radiant state of matter, in which the molecules were relatively as far apart as compared with those of a gas as the molecules of a gas were as compared with those of a liquid. But it remained for Crookes to actually demonstrate, by the aid of his high vacuum tubes, that such was apparently the case.

Crookes directed his attention mainly to the influence proceeding from the cathode, and conceived that electrified particles were projected in straight lines in what he termed "a mean free path" from it. That this was possible, he contended, was due to the fact that the few remaining molecules of gas within the tube were so far

apart that they could move in such a path without jostling one another and could thus acquire a high velocity and produce effects otherwise impossible. A main effect noticed was a certain bombardment of the walls of the tube by the molecules projected from the cathode, producing a fluorescence of the glass, and capable of being intercepted by solid bodies placed in their pathway within the tube. An illustration of this interception and fluorescent effect was noted in connection with Fig. 31 in Chapter III. of Part II.

These views of Crookes regarding the nature of the cathodic rays may be termed the English view in contradistinction to the German view which assumes the cathodic rays are a special kind of vibratory motion of the ether.

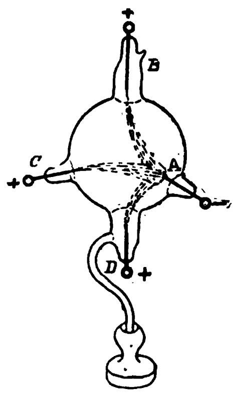

FIG. 48.

The following beautiful experiment from Crookes illustrates the projection of a cathodic stream in a straight line from its source, and represents a condition of affairs which will often occur to the experimenter.

Take a globular Crookes tube similar to the

one shown in Fig. 29 and reproduced in Fig. 48 and connect the electrodes B, C and D alternately to the anode of the induction coil and the cup electrode A to the cathode. If there is a low vacuum in the tube the electric discharge will proceed from the cathode by the shortest path to the electrode to which, for the time being, the anode has been connected. This is clearly shown in the illustration, Fig. 48.

If, however, the vacuum in this tube be raised to a millionth of an atmosphere a very different effect will be obtained, for although the anode be connected to either B, C or D, the cathodic stream will be concentrated on the glass wall of the tube, as shown in Fig. 49. It will be seen that the stream will be projected from the cup-shaped electrode A in straight lines which will be brought to a focus (due to the shape of the electrode A) and then concentrated as shown, totally irrespective of the position of the anode terminal. This shows that the action of the cathodic stream depends on the degree of vacuum in the Crookes tube.

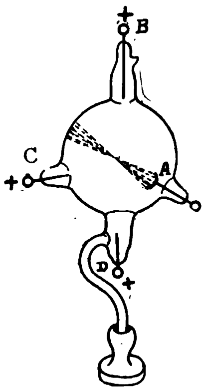

FIG. 49.

It will be observed that so far as relates to Crookes the cathodic rays were investigated *within* the tube or bulb, and it was not supposed they passed through the glass walls of the vacuum tube.

Hertz showed that the cathodic rays passed through thin sheets of metal placed within the bulb, but it was reserved for Paul Lenard, his pupil, to establish the existence of the cathodic ray outside the bulb by providing a small window, so to speak, of aluminum in the glass wall opposite to the cathode. Through this window, which ordinary light could not penetrate, the cathodic rays freely passed, but only to a distance of about three inches. This actual existence of a cathodic ray outside the glass bulb he demonstrated by noting that fluorescent effects (common enough within the bulb) were now produced outside it, as well as photographic effects. The eye perceived no effect as would have been the case had the cathodic rays been similar to light, although Lenard considered the cathodic rays to be of the same nature as light rays. It was Lenard who pointed out that the cathodic rays outside of the tube could be deflected from their straight course by a magnet. Lenard, indeed, showed that cathodic rays might

pass through substances opaque to light and cast "shadows" of other objects less opaque, and that these "shadows" might be impressed upon an ordinary photographic plate and be developed and fixed in the usual manner.

The special properties of the cathodic rays appear to be briefly as follows:

(1.) That they leave the cathode in straight lines independent of the position of the anode.

(2.) That they exhibit themselves only in very high vacua.

(3.) That they produce a luminescence of the rarefied gases and a fluorescence or phosphorescence of the wall of the tube or bulb, or of certain substances contained within the tube.

(4.) That they are deflected from their straight course by a magnet exactly as if they were an electric current moving along a conductor.

(5.) That particles of material from the electrodes are carried along the line of movement, thus often coating the walls of the tube with these particles.

(6.) That they may be concentrated or focused to a point by giving the cathode itself the form of a concave mirror or be otherwise distributed by changing the shape of the cathode.

When a current of electricity is passed through

a Crookes tube the cathode is heated, as would be the case in an electric arc in the air where the negative pole is commonly the hottest. An experiment which you can readily try yourselves with your induction coil is to connect the terminals of the secondary with a piece of fuse-wire or fine lead wire; when the current is passed through the coil the end of the wire attached to the negative terminal becomes most heated and melts.

And now comes Prof. Roentgen, the importance of whose discovery consists largely in the interest he has excited throughout the world and the marvellous impulse he has given to experimentation on both sides of the Atlantic. While Lenard had led his cathodic ray outside the bulb and noted fluorescent, phosphorescent and photographic effects, as well as the penetration of thin layers of substances of different densities, yet when Roentgen produced similar effects at comparatively enormous distances from the tube, and to the extent of depicting the bones within the living flesh, the world's amazement knew no bounds. He transformed what had been merely an interesting scientific fact into a positive power for good, which will affect the entire human race.

Roentgen claims that his effects are due to a

different form of radiation from that of Lenard and his predecessors of the cathodic ray, and offers in main proof of this contention that while, as has been stated, the cathodic ray can be deflected by a magnet, the Roentgen or X Ray is not so deflected. In view of the importance of Prof. Roentgen's contention the reader's attention is called at this point to the original communication to the Würzburg Physico-Medical Society of December, 1895, which is reproduced in full in Appendix A.

This communication will bear most careful study, since but little has been added to Prof. Roentgen's carefully prepared announcement by subsequent investigation.

It would be beyond the scope of this work to here enter into a discussion as to whether the X Rays are Lenard rays or are ether vibrations transversal as in the case of ordinary light or longitudinal as Roentgen shows a disposition to believe.

Of the host of investigators who have rushed into the examination of the X Ray, while some lean toward the longitudinal wave-theory and some towards the transversal wave explanation, and some towards the belief in a stream of electrified particles, the opinion would now seem to

be gaining that the resemblance between the Lenard rays (that is, the cathodic rays) outside of the vacuum tube and the X Ray, is a very close one. This latter view has, perhaps, been most clearly enunciated in actual demonstration by the experiments of Battelli, described in *Nuovo Cimento* for April, page 193, and commented upon by the London *Electrical Review* of June 12, 1896.

Battelli found that by wrapping a piece of sensitive film with black paper (to protect it from ordinary light) and inserting it inside a Crookes tube in the path of the cathodic stream, that the film was acted upon and photographic impressions were made on the film. To prove that the X Rays were actually present in the cathodic stream and were not developed when the cathodic stream struck the paper, Battelli used protected sensitive film both inside and outside the Crookes tube. The film inside the tube was in the path of the cathodic stream, while the film outside the tube was exposed to the fluorescence excited on the glass of the tube. The inside film was always most acted upon, photographically, showing that the fluorescence of the "anticathode" (substance struck by the cathodic stream) has a far weaker photographic effect than the direct action of the cathode rays.

Other experiments tried seemed to favor the idea that the cathode rays include the Roentgen rays, for Battelli found that when a sensitive film was placed inside a Crookes tube in the normal path of the cathodic stream, which, however, was deflected by a magnet, that the film was nevertheless acted upon photographically by some invisible part of the radiation from the cathode, which had not been deflected by the magnet. He also demonstrated the existence of photographic action in the cathodic stream deflected by the magnet. From this Battelli concludes that the X Rays already exist inside the tube before collision with an anticathode, and that X Rays are produced in the tube along with the ordinary cathode rays.

The reader should bear in mind that these experiments are opposed to the idea now most generally entertained, namely, to the effect that the X Ray arises at some substance ("anticathode") which is struck by the cathodic stream in some part of its pathway. In this sense the X Ray has been termed an anticathodic production.

The view has been expressed by a number of excellent authorities that the X Ray has a resemblance to sound waves in its behavior. A sound wave, it may be remarked, is a longitudinal wave occurring in our atmosphere,

but such wave has not as yet been discovered in the ether. That the X Ray is such a wave in the ether was Roentgen's original surmise.

Mr. Tesla believes the X Radiation to be a stream of material particles projected from the cathode, capable not alone of penetrating the glass walls of the bulb or tube but also of being projected onwards into space, in greater or less degree penetrating some substances like flesh, leather, wood, etc., and arrested by other substances like metals, bones, etc. According to this view a " bombardment " outside of the tube may be conceived of similar to that long recognized to exist within the tube.

Many observers of the French school are of the opinion that the X Ray is of the nature of light, namely (in the lack of a better descriptive term), invisible or black light.
invisible or black light. It will probably be found and measured beyond the visible spectrum.

Happy the discoverer of the nature and true source of the X Ray.

Enough has been said to afford the experimenter at least a preliminary basis upon which to work and which he can extend at his leisure by further references.

CHAPTER III.

THE SOURCE OF THE X RAY AND HOW DEMONSTRATED.

PROF. ROENTGEN had something to say as to where the X Ray came from and it will be interesting at this point to quote from his communication:

"(12.) After experiments bearing specially on this question, it is certain that the spot on the wall of the discharge apparatus, which fluoresces most decidedly, must be regarded as the principal point of the radiation of the X Rays in all directions. The X Rays thus start at the point at which, according to the researches of different investigators, the cathode rays impinge upon the wall of the glass tube. If one deflects the cathode rays within the apparatus by a magnet it is found that the X Rays are emitted from another spot—that is to say, from the new termination of the cathode stream. . . . I therefore come to the conclusion that the X Rays are not identi-

cal with the cathode rays, but that they are generated by the cathode rays at the glass wall of the discharge apparatus."

This view of Prof. Roentgen has been enlarged upon as experimentation, has progressed to the extent that not only is the fluorescent spot on the glass considered to be a source of the X Ray but also any substance placed within the tube against which the cathodic stream impinges is in like manner a source. This leads to the general adoption of the theory that the X Ray is at least anticathodic, until as we have pointed out, Battelli and others put forth other explanations.

One of the earliest experiments made in this country demonstrating a point of origin for the X Ray and that this might be from an anticathodic substance independently mounted within the tube was made by Dr. Morton and communicated to *The Electrical Engineer*, appearing in the issue of March 25th, 1896,

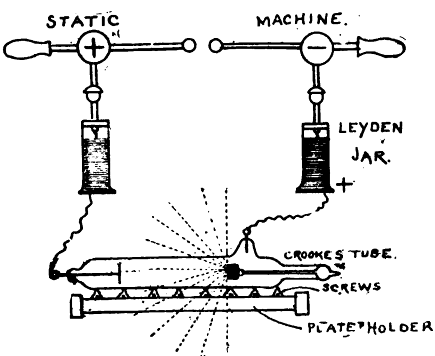

FIG. 50.

The tube used in the experiment described in the above journal was a long reflecting tube having a cathode at one end and a block of sulphide of calcium near the other end. Fig. 50 will show how the tube was placed over a photographic plateholder on the slide of which were arranged forty little screws standing on their heads. These forty screws were set one inch apart in five rows of eight screws each. When the static machine (which may be replaced by an induction coil) was excited the cathodic stream was projected upon the cube of sulphide of calcium and X Rays were developed as shown by the dotted lines in the illustration. The photograph resulting from this arrangement is reproduced in Fig. 51 (with Plates at the end of the book) which shows that the third screw from the bottom in the middle row casts no shadow and was therefore directly under the point of greatest intensity of the X Rays. This screw was directly under the edge of the sulphide of calcium nearest the cathode. The other screws cast shadows which correspond exactly with a radiation from the block of calcium as a source. A further exemplification of this may be found in the focus tubes already described. The amateur may repeat the photographic features of this experiment with any form of tube

and thus determine for himself, photographically, the source of the X Ray in his own tube.

The question still remains open, however, as to whether the X Ray actually springs into being at the platinum or other anticathode placed independently within the tube. But no matter what view is held it still remains true as a matter of fact that the X Rays are projected in all directions from that side of the reflector opposite to the cathode, forming what may be called a " hemisphere of X Ray activity " and a " dark hemisphere " in which practically no X Rays will be found. This is clearly shown in Fig. 52 (frontispiece) which illustrates a simple focus tube having a cup-shaped cathode A, of aluminum and a flat disk of platinum, B, placed at an angle of 45°. For clearness of explanation the cathodic stream is indicated as short blue arrows projected towards the reflector B, the X Rays emanating from the latter as indicated by the longer red arrows.

These hemispheres of activity and non-activity may be determined either photographically or fluoroscopically as the " field " may be explored with the fluoroscope and the sharp line of demarkation between the two " hemispheres " very clearly seen. Within the limits of this hemisphere of activity an object opaque to the X

Rays will cast a shadow invisible to the eye, unlike the shadow cast by ordinary light, but possible to detect by the image it produces upon the photographic plate or upon the fluoroscopic screen.

CHAPTER IV.

X RAYS AND THEIR RELATION TO VACUUM.

UPON referring back to Figures 48 and 49 it will be remembered that Crookes discovered that after a certain degree of exhaustion of the tube was obtained a true electric discharge no longer took place from one terminal to the other and that if he continued to pump out the air, so that a higher vacuum was produced, new phenomena were observed.

The most important of these were that the discharge from the cathode was projected straight across the tube independently of the position of the anode and that the glass walls of the tube were thrown into a brilliant fluorescence. It is at this stage in the life-history of the vacuum in the tube that the production of the X Ray begins, and in speaking of a "low vacuum" from this time onwards, we refer to such a vacuum as will just begin to permit of the production of an X Ray.

As sold by the manufacturers the Crookes

tubes purport to be adapted for certain lengths of spark; for instance, tubes are sold for $1\frac{1}{2}$, 2, 3, 4, 6 inch, and greater lengths of spark as given by induction coils. This is correct enough in one point of view, namely, that the vacuum tube when purchased must not possess a vacuum which offers too great a resistance for the electric pressure of the coil to overcome. Thus, if you have an induction coil giving a two-inch spark, it would not do to buy a Crookes tube the resistance of whose vacuum could not be overcome by the two-inch spark. From another point of view it is the experience of practice that a tube bought at a low vacuum is by use electrically raised to a higher vacuum which will, sooner or later, get beyond the capacity of any induction coil to overcome. This electrical increase of vacuum is most noticeable in tubes of the focus type in which platinum is employed both as anode and reflector; it is less noticeable in tubes whose electrodes are composed of aluminum. In fact, the vacuum of a Crookes tube is a constantly changing quantity and can never be relied upon to remain constant. As a consequence, the cathode rays change with every change in the vacuum and so equally do the X Rays. In actual practice the experimenter must not meas-

ure his work by any given length of exposure, but rather must judge of it by aid of his experience with the fluoroscope. A few brilliant flashes of the X Ray as shown by the fluoroscope will produce effects upon a sensitive plate that hours of exposure to a more moderate X Ray will fail to accomplish. It is for this reason that the experimenter must make himself familiar with that stage of vacuum in his tube adopted to his work and how to produce it.

In discussing this problem of the proper manipulation of the vacuum to get satisfactory X Ray effects it is desirable to consider, first, the raising of the vacuum electrically and, second, the lowering of the vacuum by artificial means.

TO RAISE THE VACUUM ELECTRICALLY.—X Ray photographing of dense or opaque objects like the thighs, head and trunk, cannot be done with a low vacuum tube. The tube must be "worked up" to a point where it will do work of this class. The method of procedure would be as follows:

The experimenter for instance has a focus tube, which is properly attached to his apparatus. The fluoroscope must be in hand and be his guide. Set the discharging rods so that a one-inch spark will pass and start the current. If there is any

blue color streaming along the inner walls of the tube between the anode and the cathode its vacuum is too low and only a weak X Ray is obtainable. If there is only a little vaporish blue it will usually soon disappear and be replaced by the absinthe-green color characteristic of good cathodic stream production; if it is uniformly blue it may require the current to be applied for several hours to cause its disappearance; if decidedly reddish or purple or white it is hardly worth while to try to raise the vacuum electrically, while if a direct arcing stream of electric discharge passes between the electrodes the tube should be re-exhausted—its vacuum is too low for practical purposes.

At certain stages of vacuum the cathodic stream is clearly seen to be a faint blue glow extending from the cathode and perpendicular to it. This glow has been demonstrated to be a stream of particles of gas shot with extreme velocity away from the cathode.

But, granting that the tube has vacuum enough to show no blue color it may still be, from the point of view of practical X Ray work, a low vacuum tube. It is working within a range where a one-inch spark will not pass between the discharging rods of the coil; al-

though it gives a fair X Ray, yet this X Ray has little penetrating power and fails to effect the fluoroscope at any considerable distance, say, for instance, four feet away.

It is at this point in the life of the tube that judgment and knack are required. The vacuum must be raised electrically. To accomplish this a moderate current must be passed through the tube continuously, the operator watching its behavior all the time with the fluoroscope, at the same time observing whether a spark jumps across the gap-space and watching the electrodes to see that they do not become too hot. When the vacuum is thus low in a focus tube the platinum may heat to a red or even to a white heat. This should be prevented either by reducing the current still more or by interrupting its flow for a few moments. In a few minutes, after passing this moderate current through the tube it will be noticed that a spark will jump across the inch space between the discharging rods; these must now be moved half an inch further apart. Again, after another interval, the spark will again jump and the rods must be again separated until another spark jumps. This process is repeated until a vacuum is reached which will force 3, 4, 6, 8 or more inches

of spark to jump across between the discharging rods, rather than pass through the high resistance of the tube. In practice, for heavy work, it is best to reach at least a six-inch spark, when the tube will work cold. It does not heat up and its X Ray is beautiful, as shown by the fluoroscope.

In this manner the tube is brought up to the point of power required for different kinds of work. If, for instance, it is proposed to take the trunk or other dense portions of the body the tube should be worked up with the same moderate strength of current all the time to the point where a 6-inch spark will pass between the discharging rods and then save it for that case.

However, it is as yet difficult to make positive assertions for a tube may be run cold and at a high vacuum and produce most intense X Rays, or again it may be run hot and with a red hot platinum and also produce them.

But suppose this electrical raising of the vacuum does not proceed as favorably as here outlined. What has taken place? The most noticeable thing is the heating of the glass; the glass walls of the tube are hotter than the hand can bear. The current must be turned off and the tube allowed to cool. The current must be

turned off and on in this way, care being taken that the tube never becomes *very* hot. By testing with the discharging rods to see what length of spark will pass, it will be noted that as the tube becomes hotter the vacuum becomes lower and the spark gap will be shorter. The electrodes now heat up rapidly and if this lowered vacuum has been produced while working with a large ampèrage there may be a sudden rush of current through the tube itself, breaking down the glass at its contact with the platinum entering wire and the operator sees the characteristic green of his X-Ray-producing tube suddenly turn to blue, then to purples and whites and soon to an arcing stream from electrode to electrode. The tube is ruined.

In the low vacuum tube the heating of electrodes to a white heat is equally to be avoided with the heating of the glass; both lower the vacuum. With experience the operator will soon learn how to raise his vacuum electrically to a desired point. At this point neither the tube nor the electrodes should heat.

So much for electrically raising a low vacuum tube to a working point. But there is another aspect to this question and that is this: By use, whether intentionally or otherwise, the vacuum

is in any event sure to rise. This is one of the greatest practical defects of the Crookes tubes at present in use. A vacuum is finally reached where the current, in the form of sparks, will pass *only* outside of the tube from electrode to electrode. This point is obviously determined by the distance apart of the portions of the electrodes external to the glass. If these electrodes are only three inches apart then the activity of the tube for X Ray purposes is at an end when its vacuum rises to a point where the potential of the coil causes a spark to jump across a three-inch air-gap rather than overcome the resistance of the vacuum. If the electrodes are 6 inches apart the same reasoning holds good and the tube's usefulness ceases when a 6-inch spark will jump from electrode to electrode externally to the glass. For this reason, to penetrate dense structures with X Rays it is essential that the external entering points of the electrodes should be far apart. This is accomplished by employing a large bulb, or better still, by elongating the glass even to the extent of fusing on glass tubes at the entrance point of the electrodes. See Fig. 34.

Finally as has been said there comes a time, and this not long in arriving, when the vacuum gets so high that no current whatever

will overcome its resistance. The tube must then be sent to be re-exhausted.

REDUCTION OF VACUUM BY ARTIFICIAL MEANS.—When it was first noted that the vacuum of a tube became raised to an impracticable point, it was lowered by putting the tube in an oven and heating it to 400 or 500 degrees, or by boiling it in oil.

But the delay and trouble of doing this may be avoided by the simple operation of heating the tube in its working position by aid of a spirit lamp or a Bunsen burner. For instance, the operator begins work with a tube whose vacuum forces a six-inch spark to pass between the discharging rods of the coil. This may not leave him enough margin of capacity in his coil, so he turns off the current and carefully heats the tube with the flame of a spirit lamp. This must be done boldly and yet carefully. The flame should be ample and swayed across the bottom of the tube, never resting in one place, until at last the entire tube has become evenly hot; then the lamp is withdrawn to a distance and the current turned on. If the sparks still fly around the outside of the tube the heating must be continued.

Finally there comes a moment when, upon

turning on the current, it passes through rather than outside of the tube, and then X Ray work may begin. The amateur will often have an exciting contest with his vacuum. Once lowered he may sometimes keep it low by using a current strength which keeps his platinum reflector (if a focus tube is employed) red hot.

But at last a point is reached when even heating with a flame—so far as is consistent with safety—fails to reduce the vacuum and again the tube is useless and must be sent to be re-exhausted.

In using a spirit lamp one precaution must be kept in mind: the alcohol will be ignited if it is brought near to the tube while the current is passing and an explosion may occur. Again the vacuum may be lowered in other ways in tubes especially constructed for this purpose. One of these ways is that described by Prof. Crookes many years ago. To the tube is affixed a small extension tube containing a chemical salt, which upon being heated by flame from the outside throws out more or less vapor.

Or, as devised by Dr. Morton, an inside carbon filament having outside electrodes is mounted within the tube. Upon passing current through the filament heat is produced, vapor thrown

out, and the vacuum lowered. See Fig. 52*a*. In this manner a tube may be worked for a long time and the vacuum be adjusted according to circumstances.

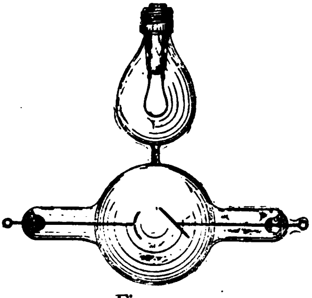

Fig. 52*a*

CHAPTER V.

TAKING THE FIRST X RAY PICTURE.

In describing a method of taking an X Ray picture it must be remembered that whether a one inch or a twelve inch induction coil is used the method of operation is the same. Also, that a simple subject such as a metallic object is taken in the same manner as the chest of a man; it is only a question of degree. Therefore, while for simplicity of description we will here choose a subject suited to a small coil it is to be understood that the *modus operandi* is the same as if a large coil were used.

We will suppose that the experimenter is now ready to proceed. He takes a plateholder containing, say, a $6\frac{1}{2} \times 8\frac{1}{2}$ inch sensitive plate whose film side is turned upward. The plate must be carefully put in the plateholder in the dark-room. The plateholder is closed by the ordinary fibre slide and may be made for either one or two plates.

Any desired metallic objects may be laid on

the fibre slide of the plateholder. For instance, let Fig. 53 represent objects picked up at random for the experiment: door-keys, eye-glasses, padlock and chain, half-dollar, aluminum medal, small wrench and tweezers. The plateholder is now ready for exposure. If desirable the plate may be wrapped in three thicknesses of black paper or in two thicknesses of black focusing cloth instead of being put in the plateholder. The paper and cloth have the slight advantage of bringing the objects exposed a little closer to the sensitive plate.

The human hand is so frequently an object of exposure and is so easily taken that we may also suppose it to be the object to be exposed in place of the metallic objects referred to above. In this case the hand should be placed in the desired position on the plateholder and three pieces of adhesive plaster (commonly to be bought at a drug store in rolls one inch in width) be used to fasten the hand firmly to the plateholder, one crossing the wrist transversely, another crossing the thumb and the other the little finger—parts most apt to move involuntarily during an exposure. The adhesive plaster will not show in the picture unless it is very much of an underexposure. Either of these prepared plates may be used for our first experiment.

It becomes first a question as to how far the plateholder should be placed from the Crookes tube. This depends upon the power of the X Ray at the command of the operator, for, as has been explained, the greater the distance of the Crookes tube from the plateholder, within reasonable limits, the better will be the definition and the more accurate the picture. With the above described objects and an induction coil giving sparks of from two to four inches in length, the distance of the plateholder from the tube may be from six to twelve inches. If larger coils are used this distance may be from eighteen inches to three feet. We are now prepared to put the apparatus into operation. For the sake of convenience we will refer to the parts of the apparatus as illustrated in Fig. 54 and described on page 88.

It is presumed that the careful operator has seen that his machinery is well oiled, that his break-wheel has been polished with sand-paper and that all the electrical connections are properly made, and that the Crookes tube is in position over the object. It must be observed that the wires leading from the induction coil to the Crookes tube do not touch the glass walls of the tube, for fear of the electrical discharge perforating the glass, also that these wires do not come

too near each other or the sides of the induction coil.

The first thing to now do is to place the discharging rods of the coil within easy sparking distance. The switch leading to the motor driving the break-wheel is now closed and the break-wheel made to run at its proper speed by adjusting the resistance in series with the motor. Having done that the motor driving the blower is started in a similar manner.

The maximum amount of resistance is now put in series with the primary of the induction coil before closing the switch of that circuit, so as to be sure a minimum amount of current will flow; the switch can then be closed and we will note what happens. In the last chapter it was shown that the condition of vacuum in the tube would be shown by the length of spark which would pass between the discharging rods of the induction coil. This is the time to apply this observation. If the vacuum in the tube is too low for good X Ray work this fact will be indicated by the shortness of the spark and may be verified by the use of the fluoroscope. It must be raised electrically as described in the last chapter. If the vacuum is too high it must be lowered by means of the spirit lamp or otherwise or, if possible, by throwing more current through the primary by

means of the adjustable resistance and thus heating the interior of the tube. By these manipulations the best X Ray producible by a given tube and a given apparatus may be made quickly available. It is obvious that the length of exposure depends not so much on the time during which the tube is excited but upon the actual time of best X Ray production.

Suppose the beginner exposes the metallic objects for about 1 to 5 minutes and the hand for from 5 to 15 minutes, he should obtain a good picture. An expert using an 8-inch spark coil and a good Crookes tube should obtain a picture of the metallic objects in less than a second and the hand in from 2 to 5 seconds at a distance between tube and plateholder of 2 feet. We would advise the beginner, however, to give ample time to all of his exposures, judging as to length of time by watching the bones of his own hand in a fluoroscope, and guided also by previous experience in developing his X Ray negatives.

Fig. 55 (see Plates at end of book) is a picture of a hand taken with a 4½-inch spark induction coil and with the first focus tube ever used in this country, it having been imported from England on April 4, 1896. This picture was taken the same day.

There are a few minor suggestions we might

make which will add to the convenience of operation :

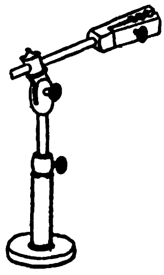

FIG. 56.

The wires leading from the secondary terminals of the induction coil to the Crookes tube should be well insulated.

They should be supported by proper stands as shown in the photograph, Fig. 54, and the accompanying sketch, Fig. 56. These are made of wood and are the ordinary chemist's laboratory stands.

The Crookes tube itself should preferably be supported on an adjustable stand as shown both in the above mentioned photograph and in Fig. 57. This is composed of a metallic adjustable upright set on a broad base, and of an adjustable horizontal portion con-

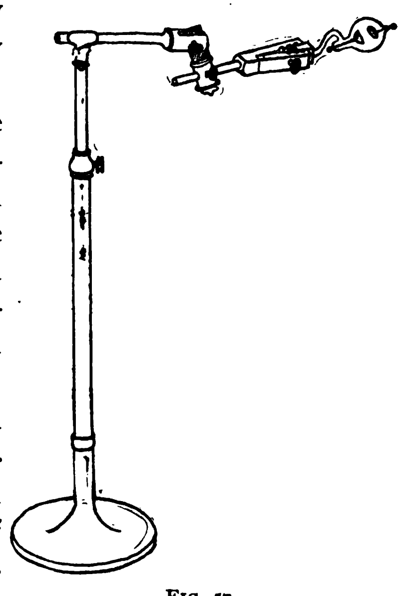

FIG. 57.

sisting of parts of the stand shown in Fig. 56. When the Crookes tube is bought it comes with small platinum eyes or loops outside the glass for the attachment of the conductors. It will be found a great convenience to permanently attach to these eyes small rings about $\frac{1}{3}$ of an inch in diameter made of common lead fuse wire. The conductors may be quickly connected and disconnected to the tube without breaking off the platinum eyes.

If the Crookes tube is of a very high vacuum and a powerful coil is used a simple contact attachment such as is here described is not sufficient, and several turns must be made by the conductor around the platinum eye.

The Crookes tube will be more safely and firmly held if its elongated extension is provided with a cube of cork perforated in such a manner that the extension of the tube will pass tightly through the hole. The cork can then be conveniently grasped by the clamping arms on the stand.

A spark-gap may be inserted in the secondary circuit of the coil. This should be at the positive pole or anode. It is said to increase the efficacy of action of the Crookes tube. Certain experiments have led to the conclusion that an X Ray

may be derived from a given Crookes tube at a lower vacuum when a spark-gap is in the circuit with it than would be possible without it.

It has been pointed out that the best way to work a tube at its highest state of efficacy is to operate it intermittently in a high state of activity. In connection with this observation it may be added that a most vivid X Ray (as represented by the fluoroscope and probably also by the negative) occurs when the platinum reflector in the Crookes tube is at a red or white heat. Practically this reflector cannot be so heated except at brief intervals, because the vacuum will be unduly lowered.

CHAPTER VI.

USING THE FLUOROSCOPE AND DIRECT PHOTOGRAPHY THEREFROM WITH THE CAMERA.

THE X Ray experimenter will find that he will have the fluoroscope very constantly in his hand, both to determine the existence of the X Ray and also its degree. The method of its use is represented in the photograph, Fig. 54, in which the operator is judging as to the probable effect of the X Ray on the photographic plate in the plate-holder by noticing the appearance of his own hand on the screen of his fluoroscope. This observation may be made anywhere within the "hemisphere of X Ray activity," indicated by (frontispiece) Fig. 52.

It will be recollected with what wonder the statement was received from abroad that objects could be seen within a closed box. Some of the earliest interesting experiments were made with aluminum and wooden boxes containing such articles as coins, scissors, pencils, etc. The experiments may be now repeated *ad infinitum.*

and it is, of course, now obvious that the objects themselves are not seen but only their shadows cast upon the screen. A pair of scissors placed within a large book, or coins within a heavy leather purse, or the sleeve buttons through the flesh of the arm, or the bones of the hand through a glove, all make simple and interesting subjects for demonstration. A block of wood from two to twelve inches or even more in thickness is readily penetrated by the X Ray.

In a more extended manner the fluoroscope will be found useful in studying the interior of the human body. Whoever has seen the bones of the hand fluoroscopically is easily convinced that one could readily see a dislocation or a fracture and such is the case. This observation is also easily made regarding the bones of the arms or legs, and less easily as regards the bones of the hips and small of the back. The shoulders and chest are easily penetrated by the X Ray, and therefore easily studied in this manner. Also diseases of the bone, such as cancer or tubercular disease, since they produce changes in the structure and therefore in the density of the bone, are equally observable.

What is true of the bone is more notably true in the case of foreign objects in the human body,

such as bullets, needles, glass, or coins, or artificial teeth which have been swallowed. Before taking a picture on a sensitive plate of almost any subject the experimenter would do well to examine it carefully with the fluoroscope; in many cases of minor surgery this is all that is necessary before making an operation. For instance, the bullet in the hand shown on the cover of this book was located before the picture was taken. It is a fact in practice, however, that the fluoroscope gives a fleeting and often indistinct view, and that for the purposes of delicate operations a fixed and permanent record upon a sensitive plate is of much higher value. It has been found by observers thus far that fluoroscopic images as presented to the eye alone are often tantalizingly vague and indistinct, not, it would seem, from want of illumination of the screen by the X Ray, but because of the "diffusion" of this X Ray by masses of muscle and other tissues which may happen to surround the bones or the foreign objects sought for.

It often becomes desirable to exhibit the fluoroscope to a large number of persons, and there are several ways of doing so to advantage. For instance, the room should be darkened and the audience put in line and allowed to come to

where the exhibitor stands with his apparatus. The Crookes tube may be placed in a wooden box large enough to receive it and its stand; the end of the box toward the audience should only be covered with a thin board or a piece of heavy cardboard; the conductors leading from the coil to the Crookes tube should pass through glass tubes in the side and top of the box. This arrangement permits the Crookes tube to be made active without any of the incidental fluorescent light from the tube appearing in the room. When all is ready, each member of the audience takes the fluoroscope in turn, places his hand in front of it, points it at the invisible tube inside the wooden box, is astonished at seeing his own bones and passes on his way rejoicing.

Another excellent way to exhibit fluoroscopic effects is to mount a good-sized fluoroscopic screen upon a frame placed in front of the box containing the Crookes tube and then the operator can put his own hand and arm, or any objects he may select, behind the screen and show the results to the entire audience at one time.

The fact is generally known that the camera will see more than the human eye and this has led to direct photography, by means of the

camera, of the shadows thrown upon a fluorescent screen. This property of the camera has been made wide use of in the photography of the heavens and the discovery of comets and stars.

Obviously the pictures thrown upon the screen in a darkened room as just described may be photographed, and to this process has been given the name of photo-fluoroscopy. The resulting picture thus taken has more strength and detail than as viewed by the eye.

The length of exposure, of course, varies with the degree of excitation of the fluoroescent crystals upon the screen, but under ordinary circumstances an exposure of from one to two minutes suffices for obtaining a good negative when a very quick plate is used. Apparatus may be bought in which camera and screen are, for convenience, combined in one piece, though this is not essential.

CHAPTER VII.

PHOTOGRAPHIC NOTES.

THE negative after its exposure to the X Ray may be taken direct to the dark room and developed. Since it is far more difficult to judge of what an X Ray exposure has produced upon a plate than in the ordinary light exposure it is well to commence developing with an old or weak developer, in order that all possible detail may be saved, or to avoid a too-rapid development resulting in a fogging of the entire plate. Bromide of potassium may also be used as a " restrainer."

As to choice of developer it is possible that there is the same latitude with X Ray negatives as in ordinary light-photography. The operator may and probably will continue to use the developer which he is accustomed to use. For the possible guidance of some, however, it may be stated that nearly all the negatives reproduced in this book have been made upon quick plates and developed by a solution made according to the following formula:

light wooden frame of such a size that it will hold the negative firmly and act as a guard to the glass, also preventing the film side of the negative from being scratched by finger nails and rings.

It is also often useful in addressing an audience to be equipped with a magic-lantern. X Ray negatives, however, do not make very good lantern slides because of the absence of contrast in them. The only way to truly appreciate the revelations of an X Ray picture of the interior of the body is to study the negative itself; next in importance, but often most disappointing, is the print from this negative; of least value, due to loss of detail and lack of definition, is the lantern slide. In connection with lantern-slide exhibits we might say that a stereopticon view can be taken by the aid of two Crookes tubes, as pointed out by Prof. Elihu Thomson, and the picture thus obtained might be thrown upon a screen by aid of the "lantern-stereoscope" recently invented by John Anderton, of England. By this means we would obtain an effect of solidity or perspective and see the interior of the body exactly as if we were using our two eyes. The beauty of such a view of the interior architecture of the human organism would far transcend

the flat view obtained by the use of the fluoroscope.

A very great aid to the operator, serving to lessen the time of exposure very materially, is to take a piece of paper coated with fluorescent crystals of tungstate of calcium and place it inside the plateholder with the tungstate crystals face down upon the film side of the sensitive plate. Fig. 57 will show the effect of using such a screen. A small piece of screen was put over the plate in the dark-room, and when the picture was taken the hand rested on the slide of the plate-holder in such a way that the X Rays had to pass through the screen as well as the hand in part of the picture. As will be seen, the portion of the hand over the screen was acted upon to a much greater extent than the rest. The reason for this is that the X Rays excited the tungstate of calcium crystals to fluorescence and thus acted upon the plate by ordinary light. Such a screen is invaluable as a time-saver in taking pictures of dense structures such as the human trunk. These screens, of any desired size, to put upon photographic plates to augment the rapidity with which the picture may be taken, are manufactured by the makers of the Edison Fluoroscope referred to on page 72.

There are a few other practical suggestions which may have been touched upon previously but which might be restated here:

Place the subject to be photographed as close to the sensitive plate as possible to get sharp definition.

The nearer you bring the Crookes tube to your subject the stronger will be the effect from your X Rays. The law of "inverse squares" seems to apply to the X Rays as well as to ordinary light. It will take 9 times as long to get a picture when the tube is 6 inches from the sensitive plate as it will when 2 inches from it.

Place the Crookes tube at such a distance from the plate that the shadows from the subject are not too divergent. The shadow-picture should be as nearly life-size as possible to get sharply defined outlines. Therefore in taking pictures of thick objects the Crookes tube should be some distance from the plate, even if it does require more time of exposure.

Time of exposure also depends on the subject and the condition of operation of the Crookes tube. It can only be determined by experiment and experience. It will be possible to obtain excellent results in case the plate is *under-exposed* by intensifying it in the manner usually followed by photographers.

In photographing a subject such as a hand and arm, the hand (being the thinnest) will naturally be taken more quickly than the arm. To get an even effect wave a plate of tin back and forth over the thin portions of the hand so as to intercept some of the X Rays part of the time.

Develop your own negatives if you can. The satisfaction of seeing the results grow under your manipulation is well worth the extra trouble. It is, besides, a most useful guide in regulating future exposures.

In developing do not be disappointed if the image does not appear on the plate in ten minutes. Have patience and keep on developing and you will probably be finally rewarded.

It is sometimes interesting to make a *positive* plate from your negatives and thus, when prints are made therefrom, obtain effects of the bones in their natural white color against a dark background.

An interesting experiment easily made is to place two or more sensitized plates, with film sides up, in the plateholder, or within black paper wrappings. Using an X Ray of moderate activity both and all of the plates will be affected, but in decreasing degree. While the first plate for instance is a full exposure for certain parts

of the interior of the body, the second is equally such an exposure as is best adapted to exhibit certain other parts, like the heart and internal organs and the interior of the bones. A great number of layers of films, or of layers of bromide paper may be arranged in this manner and thus an equally large number of varying revelations of the same interior be gained at one exposure to the X Ray.

PART IV.—SURGICAL VALUE OF THE X RAY.

CHAPTER I.

NORMAL ANATOMY.

GREAT as is the interest which has been excited by the X Ray in the scientific laboratories of the world, among electrical engineers, photographers, students and amateurs, still greater is its interest to the physician and surgeon, for in its application to surgery lies its highest field of usefulness to humanity. The physician has ever been on the alert to explore the mysteries of the human body, and to the already familiar methods of exploration, such as the opthalmoscope, stethoscope, cystoscope, the percussion hammer and the probe, is now added the revelations of the X Ray.

Even as yet, in the undeveloped stage of Professor Roentgen's discovery, there can be little doubt that no more valuable means of

diagnosis has ever been afforded to the science and art of medicine.

Conspicuous among the revelations of the X Ray are those relating to normal anatomy. It might be claimed that the bones of the animal body could be studied from prepared skeletons but such artificial arrangements of the bones can never, in reality, give their exact relations as well as the X Ray picture, nor in any sense afford us a correct idea of these relations in the varied postures permitted by the changing position of the bones which compose the joints. Also the stages of growth of the bones in children may be pictured. This is beautifully shown in the illustration of the entire skeleton of an infant nine weeks old reproduced[1] in Fig. 59, where there is an obvious absence of bony structure in the region of the joints.

To the comparative anatomist the X Ray furnishes an opportunity to study in like manner the bony structure of the lower animals. The X Ray picture of the flounder shown in Fig. 60 exhibits most accurately the delicate and almost lace-like outline of bony structure. In the stomach of the flounder is shown the minute shellfish upon which he had fed. The hook was firmly imbedded in the flesh before the picture

[1] This illustration, as well as those following which are reproductions from photographs, will be found at the end of this volume.

was taken and was attached to the catgut snell, which does not show. In a picture not here reproduced two rats swallowed by a boa-constrictor were shown in the snake's stomach.

The normal anatomy of a woman's hand is shown in Fig. 61 and Fig. 62. Incidentally it may be noted in Fig. 61 that the diamonds in the ring have failed to obstruct the X Ray whereas the gold ring and bracelet in Fig. 62 have thoroughly obstructed it. Many other instances of normal anatomy will be observed among the illustrations.

In Fig. 63 the bones of the foot are illustrated; in Fig. 64 the bones of the shoulder, and in Fig. 65 the bones of an adult female pelvis are shown.

In Fig. 66 and Fig. 67 may be contrasted an ordinary photograph of a man's head and an X Ray picture of the same.

In short, interesting facts concerning the normal anatomy of structures may be observed by a study of almost any of the X Ray pictures in this book, even though some abnormal features may be present. We would particularly call the reader's attention in this regard to the cup-shaped character of the shoulder joint in Fig. 64.

In teaching the anatomy of the blood vessels

the X Ray opens out a new and feasible method. The arteries and veins of dead bodies may be injected with a substance opaque to the X Ray, and thus their distribution may be more accurately followed than by any possible dissection. The feasibility of this method applies equally well to the study of other structures and organs of the dead body. To a certain extent, therefore, X Ray photography may replace both dissection and vivisection. And in the living body the location and size of a hollow organ, as for instance the stomach, may be ascertained by causing the subject to drink a harmless fluid, more or less opaque to the X Ray, or an effervescing mixture which will cause distension, and then taking the picture.

CHAPTER II.

FRACTURES, DISLOCATIONS, DISEASES OF THE BONES AND DEFORMITIES.

IT is already apparent from an inspection of the illustrations in Chapter I. that irregularities or deformities of the bones may be clearly indicated by X Ray pictures. By this means it is possible to detect and diagnosticate fractures and dislocations, and what is very important to decide in a given case, whether it is a fracture or a dislocation, or both together, as often happens, which exists. We may also discover other deformities of the bones and even diseases like tuberculosis and cancer which, in destroying the bone structure, have varied its density. Many illustrations exhibit the marrow cavity of the bones. Moreover, the progress of the union of the bone after it has been set in splints may be studied in its various stages, or even the correctness of the setting of the bone may be determined and rectified if found wrong.

To one who has already had experience with

the revelations of the X Ray in showing conditions of the bones far different from those assumed to exist by ordinary means of diagnosis it seems impossible that any well-equipped hospital in the land can do justice to its patients if it does not possess a complete X Ray outfit.

In Fig. 68 we have an example of a fracture of a bone of the forearm, which for some reason had for a long time failed to unite and was continued in splints to bring about union. The picture was taken through half-inch board splints and bandages; the pins shown fastened the dressings of the splints.

In Fig. 69 is represented a case of what is surgically called a Colles's fracture. This is a fracture of the bones of the wrist. The patient had slipped upon the ice a year prior to the taking of the picture and the wrist was practically well but showed some deformity and stiffness. The case appeared like one of dislocation, and it was not until the X Ray was brought to bear upon it that its true character was ascertained. It will be seen by an inspection of the picture that the two bones of the fore-arm at the time of the fall were broken off short at their lower ends and that the shafts of the bones had been driven into the broken ends telescopically. The picture

was a revelation to the surgeon who brought the case. Alongside of the broken wrist is shown the normal wrist for purposes of comparison, and it is strongly advised to take corresponding limbs in order to compare the diseased with the normal parts. If this is not done it often happens that enlargements and minor deformities pass unnoticed.

In Fig. 70, by the same comparative method, is exhibited an old and unsuspected ununited fracture of the tip of the large bone of the leg at the ankle, together with a separation of the two bones of the leg at the same point, causing much deformity and some pain. Between the two bones is seen an unnatural bony union. Upon seeing the picture the surgeon exclaimed: "My entire plan of operation must be changed. I could not have known at this stage of the case except by the X Ray that the bone had failed to unite and was still a broken bone."

Fig. 71 exhibits the case of a child's elbow joint in which the arm could not be fully extended in a straight line. The picture shows it to be due to a probable fracture sustained about a year previously while wrestling.

Fig. 72 is an instance both of normal anatomical features of the bones of the hands, and

also of the very slight changes in the left wrist (seen on the right hand side of the picture) produced by severe rheumatism of over a year's standing. So localized was the pain to this one wrist that it was thought some foreign body must be present; none was shown. The accuracy of the picture was due largely to the fact that the Crookes tube was placed two feet from the sensitive plate during the exposure of about two minutes.

Fig. 73 represents a chest and shoulders of a young man who had disease of the right shoulder of five years duration, and about which no accurate diagnosis could be made. The sound shoulder was taken for comparison with the diseased one. In this as in all cases the revelation of the *negative* was much more full and accurate than could be gained from an inspection of a print, but it is apparent even in the latter that the head of the large bone of one arm is sunken in at the shoulder and has lost its rounded contour and some of its substance at the top. It is probable that the disease is tuberculosis of the bone.

In Figs. 74 and 75 are exhibited congenital deformities of the bones of the hand in children, and of the flesh also, which are to be or have been rectified more or less by surgical operations.

CHAPTER III.

STIFF JOINTS (ANCHYLOSIS).

IT is often important to decide whether the fixed posture of a stiff joint which has been injured by fracture or disease is due to a growth of bone or to a growth of soft tissue, both of which may equally obstruct its movement, while one is far more difficult to relieve than the other. The X Ray makes a positive diagnosis as to this difference. The bony bands or adhesions are opaque to X Rays while the fibrous bands are transparent.

Fig. 76 is an illustration of a stiffened knee joint in a child twelve years of age. No bands of bone crossing the joint are shown; it is therefore fibrous and easily curable.

On the contrary, Fig. 77 illustrates in a very clear and decisive manner bands of bony tissue firmly binding the joint and preventing movement. This condition followed a dislocation and fracture of the elbow joint.

CHAPTER IV.

THE X RAY IN DENTISTRY.

THE extensive applications which can be made of the X Ray in dentistry were early pointed out.[1] The density of the teeth is greater than that of the bone which surrounds them, and for that reason pictures of the living teeth may be taken by the X Ray even of each wandering fang or root, however deeply imbedded in its socket. Also, children's teeth may be photographed before they have escaped from the gums, and the extent and area and location of metallic fillings may be sharply delineated, even though concealed from the outer view. The lost end of a broken drill may be found, and, what is most interesting, the fact that even the central cavity of the tooth may be outlined, so that diseases within the tooth may be detected. It is equally obvious that diseases of the bone and other tissues in the neighborhood of the teeth may also be observed.

[1] *Dental Cosmos*, June, 1896.—Paper read before New York Odontological Society, April 24, 1896, by Dr. W. J. Morton.

Fig. 78—a picture of a non-living subject—is a front view of a skull, and shows not only the location of the teeth where concealed within their sockets but also the outlines of the cavities of the teeth themselves.

Fig. 79 illustrates the detection of an eye-tooth in an adult which never, as yet, has escaped from the gums.

CHAPTER V.

FOREIGN OBJECTS IN THE BODY.

ONE of the first applications of Roentgen's discovery was the detection of foreign objects in the body, and this application of the X Ray to surgery renders it of inestimable value.

No one but a surgeon knows the difficulty of cutting the flesh in search of a concealed object like a bullet or a needle.

In case of war an X Ray outfit must prove to be a necessity in the location of bullets lodged within the body. Even now the English War Office is reported to have sent two X Ray outfits up the Nile with its military expedition, and our own Navy Department is said to contemplate equipping each of its vessels with similar apparatus.

Could a localization of the bullet in the body of the late lamented Garfield by means of the X Ray have been made his life might have been saved. Also in the case of another President an unsuspected badly united fracture of a bone of

the leg, sustained many years before by a fall from his horse in a historical battle, could have been detected by means of the X Ray and an operation performed to relieve it.

Fig. 80 (also presented on the cover of this book) is a typical illustration of the value of the X Ray in the location of foreign bodies. On July 4th last, while celebrating, the owner of the hand, in withdrawing cartridges from a pistol, accidentally discharged one and shot a bullet into his hand. It was probed for long and carefully and the search abandoned. Two minutes of X Ray exposure and a few minutes occupied in developing the plate revealed the bullet firmly wedged between two bones near the wrist and in a position almost impossible to detect by the aid of the probe. The bullet had entered the hand between the second and third fingers. The operation for removal was now a very simple one and within a few minutes the patient was shaking his bullet as a trophy in an aluminum match-box.

Fig. 81 represents a picture taken before the New York County Medical Society [1] (the exposure being made in the course of the address and immediately developed and passed about the audience) of

[1] Address upon "The X Ray and some of its Applications in Medicine," by Dr. W. J. Morton on April 27, 1896.—New York *Medical Record*, June, 1896.

a hand supposed to have a piece of a needle in it. The hand was enveloped in bandages. The location of the needle was clearly shown and it was successfully removed the next day.

Figs. 82 and 83 show a needle in the adult foot. Two pictures were taken for the reason that an object concealed within the body obviously can only be effectually located by taking two or more views at an angle.

The first view shows the needle beneath the bone somewhat fore-shortened; the second gives a side view. Comparing the two views the surgeon extracted the needle in two minutes.

Fig. 84 illustrates the localization of two pieces of steel in a blacksmith's fore-arm.

Fig. 85 is an extremely interesting exhibition of X Ray localization. The patient, an adult, had been confronted by an insane man a year and a half before this picture was taken and shot in the mouth with a bullet from a ·38-calibre revolver. Four teeth were knocked out and the patient was sent to a hospital but the bullet was not found. Some months subsequently a sore appeared on his neck and particles of gunpowder came out, but no bullet. The X Ray picture shows the bullet in the *chest* behind the junction of collar-bone and breast-bone, and it is soon to be removed. The

picture illustrates this fact that even though a foreign body may be behind bone it can nevertheless be located as bones are partially penetrable by the X Ray. In this case the location of the bullet without the X Ray had proved to be absolutely impossible, and under these circumstances no operation was justifiable, although the man was permanently disabled and was much emaciated.

Keeping in mind the fact that substances are opaque to the X Ray in ratio to their density, it is clear that foreign objects in the body, such as abnormal concretions of bone-like materials, termed calculi, which occur in various organs of the body, can be distinguished in X Ray pictures. An exact diagnosis of the existence of these foreign bodies preliminary to the operation is of great value, to determine in the first instance their presence, and in the second their locality. The relations of density are clearly indicated in Figures 86, 87 and 88. Fig. 86 shows an X Ray picture of a normal kidney and one containing calculi. Fig. 87 shows two kidneys containing uric acid calculi. Fig. 88 shows several of these calculi removed and exposed upon the same plate with a brass bell-clapper, a copper ball and a lead bullet. The

calculi appear about as opaque as the metallic objects. It should be mentioned that these are specimens taken from a pathological museum, and were taken preliminary to X Ray exposure in the living subject.

CHAPTER VI.

SOFT TISSUES AND LOCATION OF ORGANS.

Soft tissues comprise all body tissues except the bones, and one of the most unexpected—and as yet most undeveloped—applications of the X Ray is not only in determining that they are the subject of disease but in locating the area over which the disease extends.

In the picture of the infant given in Fig. 59 the liver is plainly shown in outline and mapped out in relation to the usual landmarks. Organs distended with gas, such as the stomach and intestines, allow the X Ray to pass freely, and thus the record of their location and size is made.

These findings in relation to the soft tissues can only be appreciated by an examination of the negatives themselves. Negatives which have been under-exposed are full of delicate, ghost-like, yet clearly defined, outlines of skin, muscle, tendon, and sometimes veins and arteries.

The mind walks in among the tissues themselves. It seems as if it were their ghost or astral forms we see depicted. Some of the negatives from which many of the illustrations in this book are taken are full of detail of this character which is lost entirely in a print. Fig. 89 gives a clear indication as to the location of a living woman's heart—the first ever seen poised among its natural surroundings of flesh and bones.

The fluoroscope may also be used to exhibit some wonderful effects in connection with soft tissue, as well as the sensitive plate. For instance, if a person be interposed between a fluoroscope and a Crookes tube we shall see the beating of the heart, the rise and fall of the ribs in respiration, the outlines of organs like the liver, the vertebræ and the greater bones, all, however, with more or less indistinctness.

CHAPTER VII.

MEDICO-LEGAL.

A VERY important application of the X Ray will be in connection with expert testimony in the courts. Court-records contain numerous cases in which the X Ray would have been of great service. Already it has been used for this purpose.

Fig. 90 shows a picture of the knees of a person which is likely to find its way into court. The patient was thrown down with violence in a trolley-car accident more than a year ago, and has suffered more or less ever since. An exposure was first made of the injured knee only and afforded no positive evidence of the seat or degree of the injury. By resorting to the comparative method, a picture of both knees was obtained (Fig. 90), which showed that the upper portion of the large bone of the leg below the knee was nearly three-quarters of an inch wider

in the injured knee than in the normal one. This was doubtless due to fracture and subsequent growth of bone. Such a picture is very convincing and would be sure to have great weight with a jury.

NOTE: The original X-Ray negative of Fig. 90 is now a court record and it is impossible to obtain possession of the same to make a half tone reproduction until the case is settled. The picture will be reproduced in future editions of this work as soon as the original negative can be obtained.

CHAPTER VIII.

CURATIVE ACTION OF THE X RAY.

MUCH interest has been excited as to the influence of the X Ray on bacteria. In February, 1896, Dr. Morton exposed cultures of the cholera vibrio, of the bacillus colli communis, the bacillus of typhoid fever and of diphtheria to the X Rays for 30 minutes and for one hour. They were from time to time compared with other cultures kept under the same conditions except for the exposure to the X Rays in the usual manner. No differences could be determined at that time between the cultures which had been exposed to the X Rays and those which had not been so exposed.

These experiments, however, were conducted in the early days of the X Ray, when it was not by any means powerful, and it yet remains with the powerful X Ray of to-day to determine whether or not in reality the X Ray possesses a germicidal action.

In favor of an influence of the X Ray upon

tissue is the experience of the experimenter that after viewing a very powerful X Ray continuously through a fluoroscope the eyes are frequently affected painfully.

Inflammation of the eyelids, upper lips and of the skin of the face generally, somewhat of the nature of sunburn, has been recorded by more than one experimenter as the result of exposure to the X Ray.

CONCLUSION.

It is difficult to say to what final uses the simple fact discovered by Roentgen that different substances are more or less opaque to the X Ray, according to their density, may be put. We have laid stress mainly upon its uses in surgery but there are several other applications of great interest.

Flaws and weldings may be discovered in metals; investigation as to the amount of metal in different ores may be made, and it will interest dealers in diamonds to know that the X Ray positively distinguishes between the true diamond and the paste imitation.

Not only can handwriting in sealed envelopes be photographed by the aid of the X Ray as in Fig. 91 (which purports to be a man's will sealed in an envelope as an experiment) but in a negative not here produced an X Ray photograph of handwriting inside the plateholder was taken even after the X Ray has passed through a human skull.

Many names have been given to pictures taken by the X Ray and to the method of so taking them. Among these may be mentioned the following: X Ray photography, shadowgraphy, radiography, cathode photography, cathography, electrography, fluorography, skiagraphy, skotography and Roentography. The term photography may perhaps have been used in some part of this book in a loose sense, but it must be understood as including in the process the handling and development of the sensitive plate as well as the agency by which it is affected.

In reading these pages up to this point one can hardly fail to be impressed with the wonderful results already achieved in this most attractive field of investigation as well as with the enormous possibilities lying dormant in Prof. Roentgen's discovery. Positive statements as to *why* and *how* are as yet out of place; almost every hour brings with it new theories and new developments, and we can confidently look forward to more definite results and knowledge in the near future—

"*For there is nothing covered that shall not be revealed, and hid that shall not be known.*" MATT. 10: 26.

APPENDIX A.

A NEW FORM OF RADIATION.[1]

BY PROF. WILHELM KONRAD ROENTGEN.

1. If we pass the discharge from a large Ruhmkorff coil through a Hittorf or a sufficiently exhausted Lenard, Crookes, or similar apparatus, and cover the tube with a somewhat closely-fitting mantle of thin black cardboard, we observe in a completely darkened room that a paper screen washed with barium-platino-cyanide lights up brilliantly and fluoresces equally well whether the treated side or the other be turned towards the discharge tube. Fluorescence is still observable two meters away from the apparatus. It is easy to convince oneself that the cause of the fluorescence is the discharge apparatus and nothing else.

2. The most striking feature of this phenomenon is that an influence (*Agens*) capable of exciting brilliant fluorescence is able to pass through the black cardboard cover, which transmits none of the ultra-violet rays of the sun or of the electric arc, and one immediately inquires whether other bodies possess this property. It is soon discovered that all bodies are transparent to this influence, but in very different degrees. A few examples will suffice. Paper is very transparent;[2] the fluorescent screen held behind a bound volume of 1,000 pages still lighted up brightly; the printer's ink offered no perceptible obstacle. Fluorescence was also noted be-

[1] Preliminary communication to the Würzburg Physico-Medical Society, dated December, 1895.

[2] By the "transparency" of a body I denote the ratio of the brightness of a fluorescent screen held right behind the body in question to the brightness of the same screen under exactly the same conditions, but without the interposing body.

hind two packs of cards; a few cards held between apparatus and screen made no perceptible difference. A single sheet of tinfoil is scarcely noticeable; only after several layers have been laid on top of each other is a shadow clearly visible on the screen. Thick blocks of wood are also transparent; fir planks from 2 cm. to 3 cm. thick are but very slightly opaque. A film of aluminum about 15 mm. thick weakens the effect very considerably, though it does not entirely destroy the fluorescence. Several centimeters of vulcanized India-rubber let the rays through.[1] Glass plates of the same thickness behave in a different way, according as they contain lead (flint glass) or not; the former are much less transparent than the latter. If the hand is held between the discharge tube and the screen, the dark shadow of the bones is visible within the slightly dark shadow of the hand. Water, bisulphide of carbon and various other liquids behave in this respect as if they were very transparent. I was not able to determine whether water was more transparent than air. Behind plates of copper, silver, lead, gold, platinum, fluorescence is still clearly visible, but only when the plates are not too thick. Platinum 0.2 mm. thick is transparent; silver and copper sheets may be decidedly thicker. Lead 1.5 mm. thick is as good as opaque, and was on this account often made use of. A wooden rod of 20 by 20 mm. cross-section, painted white, with lead paint on one side, behaves in a peculiar manner. When it is interposed between apparatus and screen it has almost no effect when the X Rays go through the rod parallel to the painted side, but it throws a dark shadow if the rays have to traverse the paint. Very similar to the metals themselves are their salts, whether solid or in solution.

3. These experimental results and others lead to the conclusion that the transparency of different substances of the same thickness is mainly conditioned by their density; no other property is in the least comparable with this.

The following experiments, however, show that density is not altogether alone in its influence. I experimented on the transparency of nearly the same thickness of glass, aluminum, calcspar and quartz. The density of these substances is nearly the same, and

[1] For brevity's sake I should like to use the expression "rays," and to distinguish these from other rays I will call them "X Rays."

yet it was quite evident that the spar was decidedly less transparent than the other bodies, which were very much like each other in their behavior. I have not observed calcspar fluoresce in a manner comparable with glass.

4. With increasing thickness all bodies become less transparent. In order to find a law connecting transparency with thickness, I made some photographic observations, the photographic plate being partly covered with an increasing number of sheets of tinfoil. Photometric measurements will be undertaken when I am in possession of a suitable photometer.

5. Sheets of platinum, lead, zinc, and aluminum were rolled until they appeared to be of almost equal transparency. The following table gives the thicknesses in millimeters, the thicknesses relative to the platinum sheet and the density :

Thickness.	Relative Thickness.	Density.
Pt. 0.018	1	21.5
Pb. 0.05	3	11.3
Zn. 0.10	6	7.1
Al. 3.5	200	2.6

It is to be observed in connection with these figures that although the product of the thickness into the density may be the same, it does not in any way follow that the transparency of the different metals is the same. The transparency increases at a greater rate than this product decreases.

6. The fluorescence of barium-platino-cyanide is not the only recognizable phenomenon due to X Rays. It may be observed, first of all, that other bodies fluoresce—for example, phosphorus, calcium compounds, uranium glass, ordinary glass, calcspar, rock salt, etc.

Of especial interest in many ways is the fact that photographic dry plates show themselves susceptible to X Rays. We are thus in a position to corroborate many phenomena in which mistakes are easy, and I have, whenever possible, controlled each important ocular observation on fluorescence by means of photography.

Owing to the property possessed by the rays of passing almost without any absorption through thin sheets of wood, paper or tin-foil, we can take the impressions on the photographic plate inside the camera or paper cover whilst in a well-lit room. In former days this property of the ray only showed itself in the necessity under which we lay of not keeping undeveloped plates, wrapped in the usual paper and board, for any length of time in the vicinity of discharge tubes. It is still open to question whether the chemical effect on the silver salts of photographic plates is exercised directly by the X Rays. It is possible that this effect is due to the fluorescent light which, as mentioned above, may be generated on the glass plate or perhaps on the layer of gelatine. "Films" may be used just as well as glass plates.

I have not as yet experimentally proved that the X Rays are able to cause thermal effects, but we may very well take their existence as probable, since it is proved that the fluorescent phenomenon alters the properties of X Rays, and it is certain that all the incident X Rays do not leave the bodies as such.

The retina of the eye is not susceptible to these rays. An eye brought close up to the discharge apparatus perceives nothing, although, according to experiments made, the media contained in the eye are fairly transparent.

7. As soon as I had determined the transparency of different substances of various thicknesses I hastened to ascertain how the X Rays behaved when passed through a prism—whether they were refracted or no. Water and carbon disulphide in prisms of about 30° refractive angle showed neither with the fluorescing screen nor with the photographic plate any sign of refraction. For purposes of comparison the refraction of light rays was observed under the same conditions; the refracted images on the plate were respectively about 10 mm. and 20 mm. from the non-refracted one. With an aluminum and a vulcanized-rubber prism of 30° angle I have obtained images on photographic plates in which one may perhaps see refraction. But the matter is very uncertain, and even if refraction exists it is so small that the refractive index of the X Ray for the above materials can only be, at the highest, 1.05. Using the fluorescent screen, I was unable to discover any refraction at all in the case of the aluminum and the rubber prism.

Researches with prisms of denser metals have yielded up to now no certain results, on account of the small transparency and consequently lessened intensity of the transmitted ray.

In view of this state of things, and the importance of the question whether X Rays are refracted on passing from one medium to another, it is very satisfactory that this question can be attacked in an other way than by means of prisms. Finely powdered substances in sufficient thicknesses only allow a very little of the incident light to pass through, and that is dispersed by refraction and reflection. Now, powdered substances are quite as transparent to X Rays as are solid bodies of equal mass. Hence it is proved that refraction and regular reflection do not exist to a noticeable degree. The experiments were carried out with finely-powdered rock salt, with pulverulent electrolytic silver, and with the zinc powder much used in chemical work. In no case was any difference observed between the transparency of the powdered and solid substance, either when using the fluorescent screen or the photographic plate.

It follows from what has been said that the X Rays cannot be concentrated by lenses; a large vulcanized-rubber and glass lens were without influence. The shadow of a round rod is darker in the middle than at the edge; that of a tube filled with any substance more transparent than the material of the tube is lighter in the middle than at the edge.

8. The question of the reflection of the X Rays is settled in one's mind by the preceding paragraphs, and no appreciable regular reflection of the rays from the substances experimented with need be looked for. Other investigations, which I will describe here, lead to the same result. Nevertheless, an observation must be mentioned which at first sight appears to contradict the above statement. I exposed a photographic plate to the X Rays, protected against light rays by black paper, the glass side being directed toward the discharge tube. The sensitive layer was nearly covered, star fashion, with blanks of platinum, lead, zinc and aluminum. On developing the negative it was clearly noticeable that the blackening under the platinum, lead, and especially under the zinc, was greater than in other places. The aluminum had exercised hardly any effect. It appeared, therefore, that the three

above-mentioned metals had reflected the rays. Nevertheless other causes for the greater blackening were thinkable, and in order to make sure I made a second experiment, and laid a piece of thin aluminum, which is opaque to ultra-violet rays though very transparent to X Rays, between the sensitive layers and the metal blanks. As again much the same result was found, a reflection of X Rays by the above mentioned metals was demonstrated. But if we connect these facts with the observation that powders are quite as transparent as solid bodies, and that, moreover, bodies with rough surfaces are, in regard to the transmission of X Rays, as well as in the experiment just described, the same as polished bodies, one comes to the conclusion that regular reflection, as already stated, does not exist, but that the bodies behaved to the X Rays as muddy media do to light.

Again, as I could discover no refraction at the point of passage from one medium to another, it would seem as if the X Rays went through all substances at the same speed, and that in a medium which is everywhere, and in which the material particles are embedded; the particles obstructing the propagation of the X Rays in proportion to the density of the bodies.

9. Hence it may be that the arrangement of the particles in the bodies influence the transparency; that, for example, equal thicknesses of calcspar would exhibit different transparencies according as the rays were in the direction of the axis or at right angles to it. Researches with calcspar and quartz have yielded a negative result.

10. It is well known that Lenard, in his beautiful investigation on Hittorf cathode rays passed through thin aluminum foil, came to the conclusion that these rays were actions in the ether, and that they pass diffusively through all bodies. I have been able to say the same about my rays.

In his last work Lenard has determined the absorption co-efficient of various bodies for cathode rays; and among other things for air atmospheric pressure at 4.1, 3.4, 3.1, at per centimeter, and found it connected with the exhaustion of the gas contained in the discharge apparatus. In order to estimate the discharge pressure by the spark-gap method, I used in my researches almost always the same exhaustion. I succeeded with a Weber photometer (I do not possess a better one) in comparing the intensity of the light of my

fluorescing screen at distances of about 100 mm. and 200 mm. from the discharge apparatus, and found in the case of three tests agreeing well with one another that it varied very nearly inversely at the square of the distance of the screen from the discharge apparatus. Hence the air absorbs a very much smaller fraction of the X Rays than of the cathode rays. This result is also quite in agreement with the result previously mentioned that the fluorescing light was still observable at a distance of two meters from the discharge apparatus.

Other bodies behave generally like air—that is to say, they are more transparent for X Rays than for cathode rays.

11. A further noteworthy difference in the behavior of cathode rays and X Rays consists in the fact that, in spite of many attempts, I have not succeeded, even with very strong magnetic fields, in deflecting X Rays by a magnet. The magnetic deflection has been up to now a characteristic mark of the cathode ray; it was, indeed, noticed by Hertz and Lenard that there were different kinds of cathode rays "distinguishable from one another by their phosphorescing powers, absorption and magnetic deflection," but a considerable deflection was nevertheless observed in all cases, and I do not think this characteristic will be given up without overwhelming evidence.

12. After experiments bearing specially on this question it is certain that the spot on the wall of the discharge apparatus which fluoresces most decidedly must be regarded as the principal point of the radiation of the X Rays in all directions. The X Rays thus start from the point at which, according to the researches of different investigators, the cathode rays impinge upon the wall of the glass tube. If one deflects the cathode rays within the apparatus by a magnet, it is found that the X Rays are emitted from another spot—that is to say, from the new termination of the cathode stream.

On this account, also, the X Rays, which are not deflected, cannot merely be unaltered reflected cathode rays passing through the glass wall. The greater density of the glass outside the discharge tube cannot, according to Lenard, be made responsible for the great difference in the "deflectability."

I therefore come to the conclusion that the X Rays are not

identical with the cathode rays, but that they are generated by the cathode rays at the glass wall of the discharge apparatus.

13. This excitation does not only take place in glass, but also in aluminum, as I was able to ascertain with an apparatus closed by a sheet of aluminum two mm. thick. Other substances will be studied later on.

14. The justification for giving the name of "rays" to the influence emanating from the wall of the discharge apparatus depends partly on the very regular shadows which they form when one interposes more or less transparent bodies between the apparatus and the fluorescing screen or photographic plate. Many such shadow pictures, the formation of which possesses a special charm, have I observed—some photographically. For example, I possess photographs of the shadow of the profile of the door separating the room in which was the discharge apparatus from the room in which was the photographic plate; also photographs of the shadows of the bones of the hand, of the shadow of a wire wound on a wooden spool, of a weight enclosed in a small box, of a compass in which the magnetic needle is completely surrounded by metal, of a piece of metal the lack of homogeneity of which was brought out by the X Rays, etc.

To show the rectilinear propagation of the X Rays there is a pinhole photograph, which I was able to take by means of the discharge apparatus covered with black paper. The image is weak, but unmistakably correct.

15. I looked very carefully for interference phenomena with X Rays, but unfortunately, perhaps only on account of the small intensity of the rays, without success.

16. Researches to determine whether electrostatic forces affect X Rays in any way have been begun, but are not completed.

17. If we ask what X Rays, which certainly cannot be cathode rays, really are, we are led at first sight, owing to their powerful fluorescing and chemical properties, to think of ultra-violet light. But we immediately encounter serious objections. If X Rays be in reality ultra-violet light this light must possess the following characteristics:

(*a*) It must show no perceptible refraction on passing from air into water, bisulphide of carbon, aluminum, rock-salt, glass, zinc, etc.

(*b*) It must not be regularly reflected to any appreciable extent from the above bodies.

(*c*) It must not be polarizable by the usual means.

(*d*) Its absorption must not be influenced by any of the properties of substances to the same extent as it is by their density.

In other words, we must assume that these ultra-violet rays behave in quite a different manner to any infra-red, visible, or ultra-violet rays hitherto known. I could not bring myself to this conclusion, and I have, therefore, sought another explanation.

There seems at least some connection between the new rays and light rays in the shadow pictures and in the fluorescing and chemical activity of both kinds of rays. Now, it has been long known that besides the transverse light vibrations, longitudinal vibrations might take place in the ether, and according to the view of different physicists must take place. Certainly their existence has not up till now been made evident, and their properties have not on that account been experimentally investigated.

May not the new rays be due to longitudinal vibrations in the ether?

I must admit that I have put more and more faith in this idea in the course of my research, and it behooves me therefore to announce my suspicion, although I know well that this explanation requires further corroboration.

APPENDIX B.

I.

EXPERIMENTS WITH ROENTGEN RAYS.

WELL crystallized tungstate of calcium made by the fusion process is extremely sensitive to the Roentgen ray. If the ray varies as the square of the distance, as there is every experimental reason to think it does, the tungsten salt is six times more sensitive to the ray than platino-barium cyanide. Plates of hard calendered pasteboard covered with the crystals permit, with a good tube, the seeing of all of the bones of the hand and arm. The fingers can be seen moving through eight inches of wood.

The next best fluorescing salt is tungstate of strontium, made in the same manner. Tungstate of barium or lead does not appreciably fluoresce. Knowing that the ray is absorbed by metals of great atomic weight, it would be natural to suppose the tungsten salts would fluoresce, and that it would be necessary to use a salt of a heavy metal, or one of great atomic complexity, but this is not true, as salicylate of ammonia crystals fluoresce with about the same power as platino-barium cyanide. The salicylate of ammonia crystals have this peculiarity that the fluorescence increases when the plate is covered more thickly with crystals, the maximum sensitiveness is reached when looking through ¼ of an inch of loose crystals. This would show high fluorescent power with low absorption.

There are a number of other salts and minerals which fluoresce. The following is a list: Subchloride of mercury, mercury diphenyl, cadmium iodide, sulphide calcium, potassium bromide, tetrametaphosphate of lead, potassium iodide, mercurous chloride, bromide lead, sulphate lead, fluorite, powdered lead glass, pectolite, sodium cressotinate, ammonia salicylate, calcium salicylate, salicylic acid.

The following are salts which fluoresce less : Powdered German glass, barium fluoride, calcium fluoride, sodium fluoride, sodium chloride, mercuric chloride, cadmium chloride, silver chloride, lead chloride, lead iodide, sodium bromide, cadmium, lithia bromide, mercury, cadium sulphate, uranium sulphate, uranium phosphate, uranium nitrate, uranium acetate, molybdic acid, silicate of potash dry, sodium bromide, wulfenite, orthoclase andalucite, herdinite, pyromorphite, apatite, calcite, danburite, calcium carbonate, strontium acetate, sodium tartrate, barium sulphobenzoic, calcium iodide, true and artificial ammonium benzoic.

It is anomalous that rock salt being practically transparent to radiant light and heat, should powerfully absorb the X Ray and give strong fluorescence.

I have found with a thick cube of fluorite, which is transparent like glass, that it fluoresces strongly to the ray, and accumulates, getting brighter and brighter ; after the bulb is disconnected it continues to fluoresce for several minutes. I have not noticed this in any other substance, except slightly in thick layers of calcium tungstate. If the hand is held before a box containing the fluorite plate, the shadow of the same may be seen phosphorescing for a minute or two after the current has been disconnected from the tube.

A curious phenomenon occurs in tubes which are best adopted for the X Ray. After obtaining a high vacuum on the pump, where the line spectrum disappears and pure fluorescence and the X Ray is strongest, the lamp is sealed off. In a short time, varying with the different lamps from one to three hours, the vacuum becomes poor. All the phenomena of low vacuum take place in light and the vacuum is really low, as ascertained by experiments while on the pump. If now the tube be kept in connection with the current it will gradually go through all the changes to a high vacuum, the line spectrum will disappear suddenly and X Rays will appear. If the bulb be left for 24 hours it requires 4½ hours continuous connection with the current to bring it back to the X Ray stage. Eighty per cent. of the lamps act in this manner ; it is independent of the kind of glass and of many variations made in the pump ; it occurs with, or without, phosphoric anhydride. It would seem that the effect was due to atomic electrolysis, free atoms being discon-

nected with the ether, only molecules being connected so as to produce pressure on the walls of the tube.

Another experiment in connection with vacuum tubes is worth recording. Edlund's theory, which has not yet been refuted experimentally, is that a vacuum is a perfect conductor of electricity. As it has been found that the resistance of any tube but slightly changes when the distance between the electrodes is increased and that the whole of the resistance is at the electrodes; also that when the vacuum is so high that no spark can be forced through it, it is easily made luminous by external electrodes, there being none in the glass. In the course of my experiments I obtained a very high vacuum through which a 12-inch spark with Leyden jars could not be forced; neither could any conduction take place with external electrodes. The tube was always dark.

It has been stated that aluminum and magnesium electrodes do not deposit on the glass. In the case of magnesium, by several hours' sparking there is formed a magnesium mirror, of lavender color by transmitted light. In the case of aluminum there is apparently no deposit. Mr. Dally, my glassblower, by oxidizing the surface of a broken tube found that the layer of aluminum was transparent and only appeared when oxidized to aluminum oxide, which was so thick that objects could not be seen through it.

I am continuing my investigations in this direction.

II.

FURTHER EXPERIMENTS IN FLUORESCENCE UNDER THE CATHODE RAY.

FURTHER experiments with the fluorescence of different chemicals under the influence of the X Ray have added a few more to the list already published. The following fluoresce; Cadium tungstate, tungstate of zinc, lithia benzoate, tannate lead, carbonate lead, salicylate potassium carbonate silver, sodium salicylate, sodium carbonate, sodium tungstate, zinc acetate, zinc chloride, zinc carbonate, molybdate zinc, benzoic acid, malic acid, diphenylamine, ruffigallic acid, pyridin nitrate.

I have so far found no salt in the following metals to fluoresce: Aluminum, antimony, arsenic, boron, beryllium, bismuth, cerium, chromium, cobalt, copper, gold, iridium, magnesium, manganese, nickel, tin, titanium.

The crystals of the following chemicals give spots of light when held close to the bulb within a dark box. The light has the glow-worm color of phosphorescence, and is due to the electric discharge and not to the X Ray: Ammonium, sulphocyanide, calcium formate, calcium nitrate, iron citrate, silver nitrate, soda, lime, zinc cyanide, zinc hypermanganate, zinc valeriate.

With plates of fluorite I have found that the phosphorescence penetrates the plate very slowly. If held before a fluorescing tube for one minute, the phosphorescence penetrates for 1-16 of an inch deep in the plate. This part, when held edgewise, is brilliant; beyond is dark.

III.

ROENTGEN RAY LAMPS AND OTHER EXPERIMENTS.

A VACUUM tube, the inner portion of which has fused to it crystals of tungstate of calcium when exhausted to the X Ray stage, gives out scarcely any of the rays; on the other hand, the tubes shine with a splendid white fluorescence. We have here a true fluorescent lamp, possibly commercial, as a very small bulk gave in the photometer 2½ candle power with an extremely small amount of energy. The white light is of a character not unpleasant, but quite the contrary. The spectroscope reveals the reason; the spectrum has strong red rays.

Tubes with aluminum electrodes become coated with transparent aluminum, which, as time goes on, gets so thick as to become visible. The X Ray is greatly diminished, not, I think, so much on account of absorption of the wave after generation, but through lack of elasticity, the concussive action or energy being absorbed by deforming the aluminum.

Silicon carbide is a conductor for high-tension current, a fact previously noted by Tesla. It is a very good conductor. I have sub-

stituted pieces of the carbide for aluminum ; no air comes therefrom ; it does not absorb air ; it cannot be melted, nor does it blacken the glass. The voltage can be increased to a point where the glass melts. It may possibly prove the most practical substance for electrodes in high vacua. The only difficulty is the contact between the carbide and platinum wire.

With all glass used for making bulbs the sodium line shows in the spectroscope ; there is evidently a decomposition due to the current, electrolytic or otherwise. Combustion tube glass has the least ; lime soda glass, that is, the glass used for dry plate photography, has the most. This latter glass is the most transparent to the X Ray, but the continuous decomposition of the glass makes it almost impossible to maintain a vacuum except when connected to the pump, and even then the effect of the current is greater in producing gas than the capacity of the pump to exhaust, but the ray is very powerful.

Experiments were made with over twelve hundred substances in the form of crystals and precipitates. Not one fluoresces through thick cardboard when the sources of energy are the arc light, a six-inch spark in air, a vacuum tube with vacuum so high that a ten-inch spark leaves it dark, and the direct rays of the sun from 11 till 2 p. m.

Another fact supporting the theory that the X Ray is a wave due to concussion is that crystals of calcium tungstate are very sensitive to agitation or slight friction, giving off light. It is also of interest to note that by a properly arranged sensitive flame and phonographic listening tubes, my assistants have made it responsive to the X Ray.

IV.

INFLUENCE OF TEMPERATURE ON X RAY EFFECTS.

FURTHER experiments with the X Ray of Roentgen and Lenard have brought out some important facts which I think will open a wide field for further experiment. It has been noticed by myself, and perhaps many other experimenters, that the relative permeability of different material for the ray was not constant. Different

tubes and conditions produced a change in the relative permeability.

It occurred to me that a great change might take place if the bulb was kept at a low temperature. I accordingly placed a tube on the vacuum pump, immersing the tube in a stout battery jar 14 inches high and 8 inches in diameter, the glass being 5-16 inch thick. The jar was filled with heavy paraffin oil. This jar was placed in a large glass jar, 12 x 12, thickness of glass 3/8 inch. This outer jar was filled with water and kept supplied with ice. When the tube was excited the ray which came through the oil to the fluoroscope was of a different character to the ray which comes from the same tube in air. The field of the fluoroscope was bright, but the hand held in front of it gave scarcely any differentiation between the flesh and the bone ; one was nearly as transparent to the ray as the other. The hand scarcely altered the brightness of the illumination, and this was true whether the tube was made weak or strong.

A sheet of crucible steel 1-16 of an inch thick, usually cuts off all the ray with tube in air. When held between the bulb and fluoroscope, under the new conditions, the steel was quite permeable, giving a fairly strong illumination of the field. A shadow was cast by a piece of steel 2 inches wide by 1/2 an inch thick. This shadow could be seen through 1/8 of an inch of steel, not only through the oil, but through the oil, water and 5/8 of an inch of glass !

In explanation of these phenomena, we may hazard the view that either the low temperature of the residual glass and gas bulb has increased the length of the waves, or the oil, etc., has absorbed the short waves and permitted the long ones to pass. If the first explanation is correct, a reversal of the condition of the experiment, that is, high temperature conditions, should give shorter waves and sharper shadows ; if the second explanation is correct, then all we have to do is to find some liquid or material that well absorbs the long waves and permits the short ones to pass, thus giving sharp shadows.

These experiments show that further investigation should be made in prismatic analysis with liquids, etc.

From continued work in this field I find that bulbs which are spherical at the point where the maximum fluorescence appears are

very liable to be pierced, not by the spark, but by a focus of bombardment, resulting in the heating to the melting point of an extremely small part of the glass.

In most cases, if the center of fluorescence is watched, a non-fluorescent portion will appear; if now the power of the coil is increased there will appear in this non-fluorescent area an extremely fine point which will grow red hot and be forced inward by the atmospheric pressure. I have seen these spots come and perforate the bulb within two seconds. I find that it occurs when the electrodes are perfectly flat, and that it proceeds as a thin concentrated pencil from the exact center coil is increased there will appear in this non-fluorescent area of this concentrated bombardment is increased and the tube can be worked at a higher power before heating. The best remedy is to permit the central ray to strike the glass at a low angle; this greatly increases the area, and prevents the trouble.

Thomas A. Edison.

APPENDIX C.[1]

THE SURVIVING HYPOTHESIS CONCERNING THE X RAYS.

BY DR. OLIVER LODGE, F. R. S.

Referring to an article by the writer which appeared some months ago (*The Electrician*, London, Eng., Feb. 7), under a title akin to the above, in which the present state of our knowledge concerning the radiation experimented on by Lenard and discovered as such by Roentgen was summarized, and an account given of the various hypotheses which had suggested themselves, it may be not inappropriate to state the present aspect of the matter, now that there has been further experimental progress.

The remarkable discovery of MM. Henry, Niewenglowski, and Becquerel that salts of zinc, of calcium, and especially of uranium exposed to strong light acquire the power of emitting, both then and afterwards, an invisible radiation which can penetrate aluminium and act on a photographic plate, has greatly strengthened the position of those philosophers who maintained that the X Rays were of the nature of ultra-ultra-violet light; and it has done this in the following way :—

The Becquerel rays are capable of some amount of polarization, and hence are certainly transverse disturbances, like light; they can also be reflected and refracted to a small extent, whereas the X Rays can be hardly at all reflected and not at all appreciably refracted. Neither kind can be deflected by a magnet, not even in a vacuum according to the experiments of M. Lagrange; and an assertion that the X Rays could be magnetically deflected after passage through an electrified plate has not been substantiated by careful experiments, made by the writer among others. Taking all these things together, and looking at them in the light of a notable dispersion theory of Von Helmholtz, to which Prof. J. J.

[1] *The Electrician*, London, Eng., July 17, 1896.

Thomson called attention in the Rede Lecture at Cambridge this year (June 10), it has become almost certain that the X Rays are simply an extraordinary extension of the spectrum—far beyond the ordinary ultra-violet—and that the Becquerel rays are a less extreme extension in the same direction.

As a matter of scientific history it may be worth recording that in an article on Roentgen's discovery, published in the *Revue Générale des Sciences* for January 30th, Prof. Poincaré hazarded the suggestion, "that all bodies which fluoresce strongly enough may perhaps emit X Rays in addition to ordinary light, *no matter how the fluorescence is caused.*" He goes on to say that although this is not very probable yet that it is possible, and should be easy to verify; and that, if true, the X Rays would no longer be producible by electrical means alone. In attempting the verification of this surmise, M. Charles Henry found and published on February 10th that sulphide of zinc emitted something which could affect a photographic plate after penetrating black paper, or even a sheet of aluminium 6 mm. thick; and M. Niewenglowski, February 17th, found the same thing for calcic sulphide. Then M. Becquerel, February 24th, repeating Niewenglowski's experiments, discovered the remarkably persistent ray-emitting power of the double sulphate of uranium and potassium. Moreover, it is noteworthy that, at a meeting of the French Physical Society held on February 7th, M. Raveau called attention to the fact that several existing theories of dispersion led to the value unity for the index of refraction of substances for very short waves, and hence argued that it was quite possible for the non-refrangible X Rays to be a variety of ordinary transverse ether waves of extremely short period.

To us at the present time the dispersion theory of Helmholtz is by far the most interesting, because it was worked out entirely on the basis of the electromagnetic theory of light. It is contained in Vol. XLVIII. of *Wiedmann's Annalen.* Helmholtz there shows, on electromagnetic principles, that ethereal radiation of smaller and smaller wave lengths should become more and more refrangible, by matter in the molecular form, up to a certain maximum; and this, of course, is ordinary dispersion; but that for waves which are shorter still, the refrangibility—*i.e.*, the refractive index of substances for such very short waves—should rapidly, indeed

almost suddenly, drop nearly or quite to zero, thus doubling the spectrum back upon itself, and giving an anomalous dispersion so great that the rays might be bent by a prism in the wrong direction (the direction beloved of examination candidates) for a certain size of wave. This state of things would be accompanied by extreme opacity, or absorption of the vibrations by the material molecules. If, however, waves existed of a kind still smaller, then the opacity would become less obstrusive ; the refractivity would likewise remain very small—either positive or negative, perhaps—but probably negative ; and ultimately, for extremely small waves of atomic dimensions, the refractivity ($\mu - 1$) would become nothing and the opacity very small.

In a general way it may be said that material atoms act as if they loaded the ether, so that coarse ether waves large enough to affect some dozens or some hundreds of molecules in a row, such as are the waves of visible light, would by reason of this loading be retarded, and therefore both reflected and refracted. All very coarse waves would be refracted about the same amount, but for smaller waves a new phenomenon would appear; as they got smaller the period of the waves might synchronize with some of the periods of atomic vibration, such vibration as enables atoms to emit light, and whenever that occurred a violent absorption might be expected, owing to the syntonic response or sympathetic resonance between the matter and the ether. This would have the effect at first of retarding the waves rather more, and of giving the well-known effects of ordinary dispersion, or the sorting out of waves roughly according to size, which we get in the prismatic spectrum. Or if the syntony is strongly marked, fluorescent and phosphorescent effects are to be expected from the jangled atoms ; and if for this or any other reason absorption is rapid, the dispersion will be what is called "anomalous," which in this connection —indeed in all possible connections—only means unexpectedly complicated.

Push the matter further, however; assume the existence of waves smaller still, so small that they cease to evoke any vibratory response from the material atoms among which they now make their way ; the ether of the interstices can hardly be appreciably loaded by the great blocks of immovable substance which now

represent the appearance of the atoms, and accordingly retardation and refraction abruptly disappear together, and true absorption also nearly ceases.

To waves penetrating ethereal interstices, matter, even conducting matter, is fairly transparent; for ordinary notions of conductivity do not apply to these intermolecular spaces; electric displacements no longer excite necessary conduction currents, even in bodies which in the gross are conductors, and accordingly there is little or no dissipation of energy, and any obstruction that exists to the passage of light of this kind is of the ground-glass or turbid-medium type, a certain percentage of the energy being scattered at each obstacle in all directions, instead of being able to excite the material vibrations which we know as heat.

This is a very bare account of the matter, but it may suffice to indicate the sort of view which is now coming to be almost universally held regarding the nature of these no longer quite X Rays. The proof is not complete, and will not be till their length has been measured, but in all probability they are ordinary transverse ethereal waves, moving with the customary velocity of light, of various grades of wave length down to 10^{-8}cm. in length, vibrating therefore some trillions of times in a second (a trillion being 10^{18}); and by the aid of this highest type of X Ray we may hope in the future to gain some diffractional insight into the actual structure and appearance of the material molecules among which they go.

In all probability they are excited by Hertz vibrations in the atoms themselves. Ordinary light may be due to mechanical or acoustic atomic vibrations; but this X kind of light is more likely due to electric vibrations, *i.e.* to surgings of the atomic charges. A globe of steel vibrating mechanically might excite ether waves a hundred thousand times the sphere in size, if it could excite them at all; but, vibrating electrically, its radiated ethereal waves would be not much bigger than the sphere itself. In other words, its vibration frequency would be multiplied nearly a hundred-thousand fold. The mechanical vibration of an atom may emit ordinary light. Its electrical vibration may quite possibly emit X Rays.

There is not lacking indirect evidence to show that what we call atomic weight is approximately proportional to atomic bulk, *i.e.* that the heaviest atoms are the biggest atoms, and that the actual

substance of all matter may be much more nearly of one uniform density than is commonly supposed. Grant this hypothesis, and it is plain why platinum or other dense material appears to be the easiest substance in which to excite the necessary electric atomic oscillations, by the impact of charged and excessively rapidly moving gaseous particles. It also suggests that the gas with the most rapidly moving atoms, viz. hydrogen, may be the best substance for the vacuum bulbs to contain ; for these would impart their charges to the large platinum atoms in the most sudden manner. It would also be plain why dense bodies should be more turbid than rare, and it is not unnatural for the turbidity to be largely a matter of atomic weight, *i.e.* bulk, than anything else, because the ethereal interstices required for the passage of the waves would in such substances be considerably filled up.

Calculate the speed of a hydrogen atom in a vacuum tube between two electrodes, kept oppositely electrified with a difference of potential corresponding to a two-inch spark between flat plates, *i.e.* 150,000 volts. The atomic monad charge is 10^{-11} electrostatic unit, so the force acting on an atom is 0.3 millionths of a dyne, over a range of, say, 5 cm. The mass of the atom is 10^{-26} gramme ; so its acceleration is 3×10^{19} C.G.S. units, and hence the speed that may be got up in 5 cm. of free path approaches very near the velocity of light, say $1 \cdot 5 \times 10^{10}$ cm. per second. If there are collisions the speed will be reduced, hence it is probably desirable that the gas should be pure, and the necessity for high vacuum is obvious. Too high a vacuum reduces the number of impinging molecules, and so weakens the intensity, but it permits the emission of the most penetrating rays, *i.e.* those with the greatest frequency number, or highest up in the spectrum.

Unless a charge is imparted to a molecule with something approaching the above estimated rapidity, it would not be likely to have electrical oscillations excited in it ; just as it is only possible to excite Hertz vibrations in ordinary small pieces of matter by some very rapid means of communicating the electricity ; otherwise the disturbed electric equilibrium restores itself in a deadbeat manner.

It is likely that the amount of energy thus consumed in the production of Roentgen radiation is extremely feeble, and that the rays

themselves are of low intensity. All that they do is consistent with the supposition that their activity depends more upon synchronism than upon violence,—which is indeed the case with ultraviolet radiation of every kind.

It is worth while to attempt to give rather a better account of the most immediately obvious results of Helmholtz's new dispersion theory—one of the last grand pieces of work before his bootless journey to Chicago. But it is to be hoped that a translation of the Paper may make it more widely known to English readers.

Results of Helmholtz's Theory.

Helmholtz's electromagnetic theory of dispersion gives as the refractive index of a quite transparent substance to radiation of frequency n (that is $n \sim$ per second) the following simple expression :—

$$\mu^2 = \frac{a^2 - n^2}{b^2 - n^2},$$

where a and b are two constants depending on the material, and to be determined by experiment.

For very long waves the refractive index is accordingly $a\ b$; for shorter waves it increases at first slowly and then rapidly up to infinity, which it reaches when $n = b$; it then becomes imaginary until $n = a$, after which it increases steadily from zero, until for very large values of n, that is, for extremely short waves, it approaches the value *unity*.

So long as the substance is really transparent it is not physically possible for n to equal b, and accordingly in such a substance, if such a substance exist, the refractive index merely increases as the waves get shorter. But perhaps a better way of stating this is to say that when n approach b it is impossible for the medium to be thoroughly transparent; and the effect of an absorption or opacity term is to pull down the infinite value of μ to a large maximum value, attained when $n = b$; and after this, instead of becoming imaginary, it rapidly drops down towards zero, which it attains, or nearly attains, before $n = a$, and it then increases again, and goes on increasing, up to the definite limit 1, which it only actually reaches when n is infinite. In the region of the maximum μ the

opacity of the medium for waves of that frequency is great, but on either side of it the opacity is moderate, and at some distance on either side is zero. In other words, a medium is transparent both for very long and very short electromagnetic waves ; but while the long waves are definitely refracted, the very short waves are not refracted at all.

Between these two frequencies there is a region of opacity and of anomalous dispersion, and in this region the refractivity may be negative, *i.e.* the refractive index may be less than 1, as has been actually observed by Kundt to be the case for some metals. Waves of high but not ultra-high frequency may be reflected and refracted a little, and these correspond with the recent discovery of Becquerel and others ; but waves of exceedingly high frequency are barely refracted or reflected at all, and these are the waves of Roentgen.

The writer suggests that a first estimate of the frequency, and therefore of the wave length, could be got by measuring the percentage of X Ray reflected from a substance of known dispersive power ; still better by measuring the deviation, if any perceptible deviation can be got. Observed deviation, introduced into Helmholtz's formula, would give only a lower limit for the range of frequency, and that only by extreme extrapolation, but it would be better than nothing.

Such is a rough account of the theory prepared by the extraordinary genius of von Helmholtz, on purely mathematical and Maxwellian grounds, in 1893 ! before even the experiments of Lenard, and indeed without any likelihood of an idea that the waves whose theoretical niche was thus provided were so soon to be practically displayed in the laboratory as an accomplished fact.

Addendum.

It is interesting to look back now to the beginning of the present year, and see how near the early spectators on the subject of Roentgen's discovery approached to what is now in all probability something like the true view of the nature of X Rays. One of the earliest published letters was from Prof. Schuster, in *Nature*, Vol. LIII. (No. 1369), which may now be referred to ; and an unpublished letter received by the writer from Prof. FitzGerald in the month of January, is so remarkable as closely anticipating the

course of discovery along several lines that the writer thinks he is not acting wrongly in printing it here without permission.

"January 24, 1896.

"About those curious photographs which you have sent me. After a variety of notions: including a suggestion that they are a new form of wave-propagation in the ether by a distortion of the *section* of vortices, which may exist all the same and remains for discovery; and a consideration of the possibilities of long waves acting on silver molecular groups, as the shorter ones act on the atoms, and their possible shaking being like the rearrangement of iron molecules, when jarred enabling them to be magnetized; and [after considering also] the action of coherers, I have discarded all these in favor of *very* short waves, ultra-ultra-violet radiations of a wave-length comparable with what would be produced by the Hertzian oscillations of electrical charges on atoms. Such ought to exist, and I think these are they.

"Objection No. I. *Transparency.*—Gold leaf is already too transparent for its conductivity for light waves; and waves that could go along in the interstices between molecules, for which matter was a sort of grove of trees with a sound going through it, a sort of turbulent [turbid] medium,—for such a material for such short waves we might naturally expect a transparency depending rather on density than on any electrical or chemical properties of the medium.

"Objection No. II. *No Refraction or Reflection.*—These, of course, go together. If there is no rapid change of medium there is neither of them, nor polarization. The velocity of propagation in the interstices between molecules is probably the same as in free ether, and we could anyway only expect an effect of the same kind as Cauchy's term in $\frac{b}{\lambda^2}$ for the dispersion that is added on to a specific refraction; and his added effect would be all that would exist, and might probably be very small, so that there would be neither refraction nor reflection.

"I would suggest trying some experiments with two slits of the diffraction kind; to look for a wave-length, though the fuzziness of the photos does not give much hope of success in this at present;

for, if I am right, the diffraction effects should be on a *very* small scale.

"Maybe we may yet learn how to photograph molecules themselves by means of these very short waves. This seems to me a very hopeful hypothesis, even though only a few hours old.

"These ultra-ultra-violet waves may also be the means by which cathode rays are projected from the outer surface of windows. Ultra-violet vibrations discharge surfaces, ultra-ultra ones may throw off cathode rays, as Lenard has observed."

Postcard Next Day.—"Since writing to you I have seen Schuster's letter in last week's *Nature*. It quite expresses my views. Ramsay has got a beautiful hand photograph. Is the effect reversible? Cathode rays make ultra-ultra-violet radiation—does the radiation reproduce cathode rays? Is this the same as discharging surfaces by light? G. F. F. G."

Part of these suggestions remain still unverified, but there is a good deal to be said for them. The discharge of surfaces by light is due, according to the writer's experiment, to convection by gaseous particles; and what are regularly moving charged gaseous particles but a variety of cathode ray?

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LIST OF RADIOGRAPHS.

ALL LIFE SIZE, HANDSOMELY MOUNTED.

Negatives by Prof. William J. Morton, M. D., New York.

Dr. Morton's collection of X-Ray pictures is without doubt the largest and finest in this country. It covers a great variety of subjects, especially those relating to surgical diseases, injuries, and malformation of the bones. His work is characterized by its great accuracy in definition, and many of his pictures taken months ago have not yet been equalled. He has particularly excelled in large work like the pictures of the trunk, etc. His pictures, many of which are here enumerated, are constantly being added to by unique cases brought to him by physicians for X-Ray diagnosis. The value of the X-Ray to the surgeons is scarcely yet appreciated.

Infant Nine Weeks Old, Life Size.—Showing with beautiful detail the bones of the skeleton, the stage of ossification, the location of the liver, stomach, heart, etc. $2.00

Adult Trunk, Life Size, From Chin to Pelvis.—Showing vertebrae, the shoulder joints, the ribs, the bones of the arm and elbow joint, the lung cavities, the heart 2.00

Adult Trunk, Life Size, Tubercular Disease of Head of Humerus.—Showing a normal and diseased shoulder joint in contrast with each other Otherwise same as above. The finest picture of the trunk thus far produced 2.00

Adult Trunk and One Shoulder Joint 1.00

Adult Head, Side View, Showing Skull and Cervical Vertebrae with Spineus Processes .... .60

Adult Head, Side View .... .60

Portion of Skull, Showing Roots of Teeth .... .60

Adult Neck, Shoulder and Chest, Showing Location of a Bullet in the Chest and Behind the Sternum 1.00

Abdominal Cavity in Region of Kidneys.—Showing negatively the absence of calculus in the kidney. Patient lying face downward, so that vertebrae and hip bones showed but obscurely .... .60

Abdominal Cavity and Lumbar Spine.—A case of suspected Potts disease in an adult .... .60

Adult Female Pelvis.—Showing Lumbar vertebrae, hip and thigh bones. Exposure 5 minutes .... .50

Pair of Large Adult Knees.—Medico-legal case. Trolley car accident; undetected fracture and osseous growth on head of tibia. Showing value of the X-Ray and of comparing in the same picture the injured and the normal bones .... .75

Knee Joint, Child Aged 12.—Showing skin, muscles, tendon of patella and bones. Case of partial anchylosis revealing that it was fibrous rather than osseous. A beautiful radiograph .... .60

Adult Ankle Joint.—Showing old un-united fracture of the internal malleolus separation of tibia and fibula. Distortion of astragalus, bone and adhesions. Upon seeing this picture, the surgeon exclaimed, "This is a wonderful revelation; my entire plan of operation must be changed. I could not have known that the bone had failed to unite." .... .75

Adult Elbow Joint.—Old fracture, one year standing; fracture of lower end of humerus and union in malposition. Anchylosis and osseous adhesion between radius and ulna. Three minutes exposure .... .60

Normal Adult Foot in Shoe.—Showing leather of shoe, nails and metal shank, flesh, tendons, and the bones of the leg and ankle, the tarsal bones and the phalanges; in short the entire osseous structure. Exposure 5 minutes. .75

Child's Ankle.—Anchylosis and active disease of the bone .... .50

Adult Foot.—With needle in it; foreshortened, top view .... .60

Adult Foot, Same Patient.—Side view showing the needle in length, operated upon with immediate success by aid of picture .... .60

Adult Foot.—Female, normal, view from sole of foot .... .60

Adult Forearm.—Blacksmith, showing location of two pieces of steel .... .60

The following are reproductions of Radiographs taken by Dr. Morton, and are referred to in the text by their figure numbers.

Fig. 54.

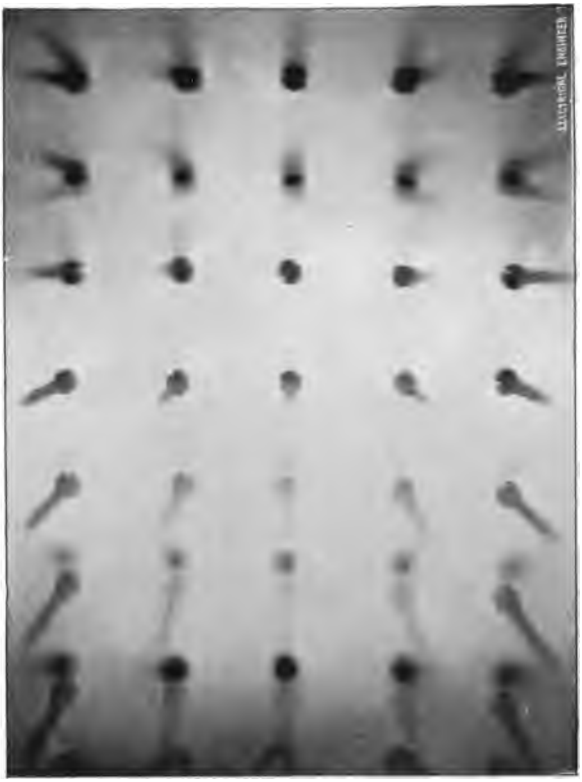

Fig. 51.

Fig. 79.

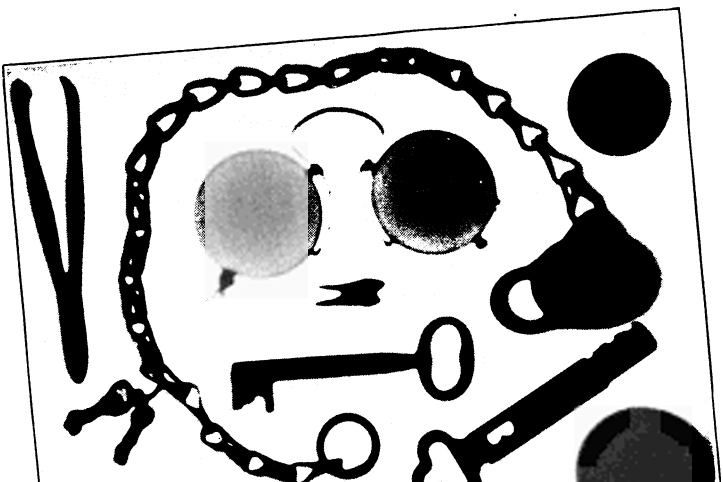

Fig. 53.

Fig. 55.

Fig. 58.

Fig. 59.

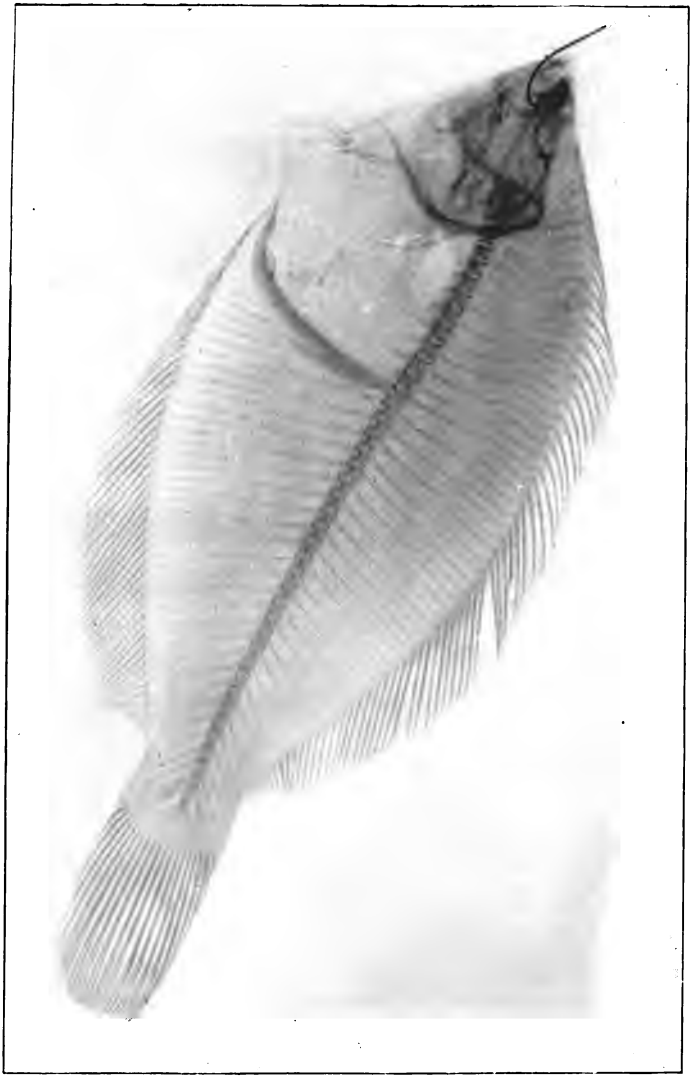

Fig. 60.

Fig. 61.

Fig. 62.

Fig. 63.

Fig. 64.

Fig. 65.

Figs. 66 and 67.

Fig. 68.

Fig. 69.

Fig. 70.

Fig. 71.

Fig. 72.

Fig. 73.

Fig. 74.

Fig. 76.

Fig. 77.

Fig. 78.

Fig. 80.

Fig. 75.

Fig. 81.

Fig. 83.

Fig. 82.

Fig. 84.

Fig. 85.

Fig. 86.

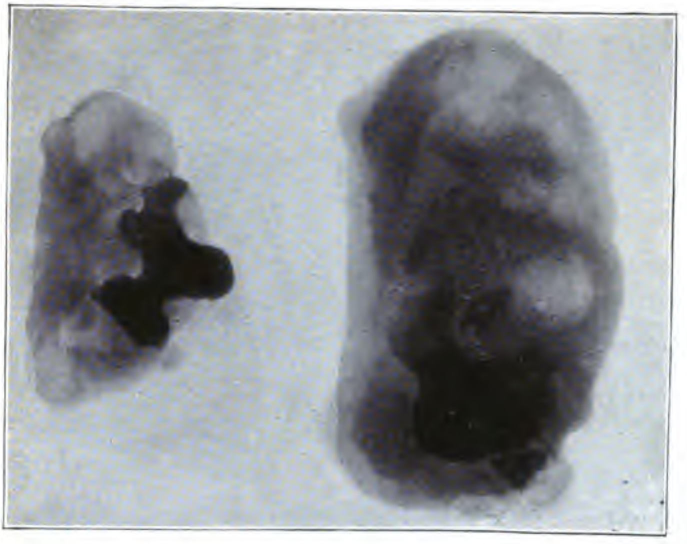

Fig. 87.

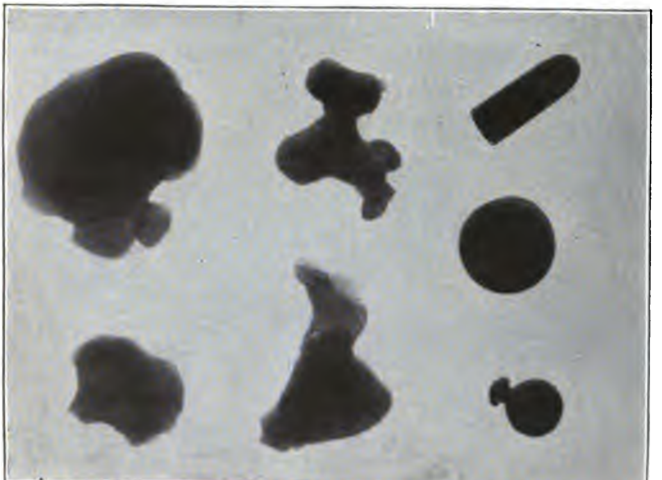

Fig. 88.

Fig. 89.